FIELD METHODS
IN
PETROLEUM GEOLOGY

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PREFACE

The rapid development of the oil industry in the past few years, together with the general recognition of the aid which can be given by geology, both to the exploration and to the development of oil lands, created a sudden and unprecedented demand for specially trained geologists, a demand which could not be immediately filled. The exigencies of powerful competition usually require that any given piece of work be done with a minimum of delay, with such forces as are immediately available. Because of this and because the fees paid were attractive to some who had neither the preliminary training nor, in some cases, the proper integrity, much poor work has been done. Competent geologists, however, have responded strongly to the demand and in a few years time have practically eliminated the undesirable elements and have so raised the standard of ability and integrity that their profession now ranks on an equal basis with any other branch of engineering or geologic work. Those not familiar with the conditions, even including geologists who are engaged exclusively in other branches of the profession, fail to appreciate what the oil geologist has accomplished and how proficient he has become in the analysis of those structural conditions found in the oil fields. This proficiency is due largely to the development of new and specialized methods and to the adapation of old methods to the new needs. It is with those methods that this book is concerned.

The authors appreciate the fact that there are already on the market a number of comprehensive treatises dealing with the theories of origin and accumulation of oil and gas, and that there is nothing sufficiently new at the present time to warrant another general treatise on these phases of the subject. There is apparent, however, a notable lack of any satisfactory systematic dis-

cussion of the minutiæ of field procedure, as it applies to th highly specialized branch of engineering geology. The prese work was prepared in an effort to fill this gap. The book mak no attempt to give a popular presentation of field procedure. It written for those who have at least moderate familiarity wi the fundamental principles of geology, surveying, and math matics, including at least trigonometry.

In the introduction, are summed up briefly and concise the various methods of oil accumulation, as they are ordinari conceived. This summary infers a knowledge of general geolo and lithology, and is presented as a basis for the discussions field methods, since most of the field work has to do with t location of various structural features.

Chapter I describes the instruments commonly used in t field work of the petroleum geologist; Chapter II outlines i strument methods in general use; in Chapter III are discuss the various geologic criteria that are used in correlating beds a identifying structures; and Chapter IV is devoted to the person of the field party, to the actual field procedure in reconnaissan and detailing, and to the preparation of the map and final repo

It is desired to emphasize the fact that there are often seve excellent methods for securing and recording the geologic da required in oil and gas development. Practice is not unifor it may vary from one district to another or from one survey another in the same district. The geologist in charge is co stantly called upon to select that method of procedure which thinks best for the time, the place, the information desired, a the conditions under which the work must be done.

It is patent that in carrying on detailed work the best resu are to be obtained when the geologist and the instrument m each know the general principles of the other's work. T often the instrument man makes poor or needless set-ups, wh the geologist in turn is inclined to scorn a knowledge of t details of instrument work and to fail to grasp the proper re tion between speed and accuracy which should govern the wo The general features of both types of work are therefore give

Mr. Cox is largely responsible for the chapters on instruments and instrument methods and jointly responsible for the rest; Mr. Dake is jointly responsible for the chapters on the identification of structure and field operations and has aided throughout; and Mr. Muilenburg is jointly responsible for the appendix and has also aided throughout.

The authors appreciate that the list of methods given is not complete. It has been said that if one waits until the manuscript is in the desired form, the book will never be published. They also appreciate that the importance of each method varies with the conditions encountered and to some extent also with the idiosyncrasies of the user. It is hoped that the work will be of assistance to many and that it will inspire all who read it with the importance of careful and thoughtful observation.

THE AUTHORS.

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INTRODUCTION

ORIGIN OF OIL AND GAS

Two explanations of the origin of oil and gas are to be considered; the inorganic, or volcanic theory, and the organic theory.

According to the inorganic theory oil and gas have been formed by chemical reactions such as the action of water on carbides, and their origin is deep seated within the earth.

The organic theory assumes that these substances have resulted from the partial decomposition, in sedimentary rocks, of organic matter, either animal, vegetable or both.

Most geologists believe that while the inorganic theory is plausible on the basis of laboratory experiments, it does not fit well with the observed facts of distribution. Consequently prospecting for oil and gas at the present time is largely, in fact almost wholly, carried on under the assumption that the organic theory is the correct one. It follows that extensive areas of igneous rocks, areas of sedimentary rocks which have been highly metamorphosed, and areas of those rocks, like the "Red Beds," which are believed to have been deposited on land and under arid conditions, are thought to be unfavorable to oil and gas accumulation because, in the igneous rocks, the conditions are not favorable either to origin or to accumulation; in the metamorphic rocks, any oil or gas that might have been present would probably have escaped; and in the terrestrial "Red Beds," the sediments would constitute a poor source as they are nearly destitute of organic matter. It does not follow that oil and gas

cannot be found near igneous rocks nor that they cannot migrate into non-organic formations. Beyond this it is not pertinent to inquire into theories of origin in a treatise on field methods.

RESERVOIRS

The accumulation of oil and gas very rarely occurs in large open cavities, or underground channels. Commonly they simply saturate the rock, filling openings, such as joints, bedding planes, and pores. Consequently the most pervious or porous rocks would be expected to form the best reservoirs; and this, in general, is the case.

Usually the best "oil sands" are sandstones, but the reservoir formation is often spoken of as an "oil sand" even when it is a limestone. True sands vary in porosity from 1 per cent. or less in the most firmly cemented quartzites, to 40 per cent. or more in loose sands of nearly uniform grain, the figure being modified by cementation; by the ratio of coarse to fine material; by impurities; and by the degree of compacting. Conglomerates may also have much pore space. Limestones vary greatly, some being very dense, others very porous. The more porous varieties usually contain much magnesium carbonate and are then known as dolomites. Shales, though porous, are usually impermeable because the individual pores are very small and are not continuous, owing to the shape of grains. Igneous rocks are rarely sufficiently open, even where favorably situated, to afford suitable opportunity for accumulation; only tuffs, agglomerates, and partly weathered igneous rocks having appreciable pore space. Secondary openings, such as fractures, shrinkage vugs, and solution cavities, add to the porosity of rocks. A fair average for the effective porosity of the productive sands in the oil fields is probably about 10 per cent.

In general, sandstones are the best reservoirs, with dolomites second, while shales form the most impervious layers. Even in non-porous, or non-pervious rocks, small quantities of oil and gas may be secured in fractures but the supply is usually very limited and its discovery largely chance.

MIGRATION

To accumulate in reservoirs, the oil and gas must migrate through the rocks. The fact of migration is universally admitted, though there is dispute as to the relative importance of the causes of migration, as to the distances involved, and as to its effect on the oil. The causes of the migration may be several. Oil is lighter than water, and gas in turn is lighter than either, so that, where they are perfectly free to do so, the three, if present together, may be expected to arrange themselves in the order of their specific gravities, with water lowest and gas highest. Hydrostatic pressure (pressure exerted by still water) and hydrodynamic pressure (pressure exerted by the deflection of moving water and in this case due to the compacting of the rocks and the squeezing out of the contained water by the weight of the overlying rocks) also influence the migration of oil, as do gas pressure and capillary attraction. Apparently the most important factor in controlling the place of accumulation is gravity, for when the dip of the containing strata is such that the forward movement is no longer assisted by this force, migration stops.

STRUCTURAL CONDITIONS FAVORING ACCUMULATION

Because natural gas is lighter than air, it will rise through the pores of the rock and escape if free to do so. Similarly oil if unhindered, will rise to the surface of the water, and drain off as springs or seeps at the water outlets. For good accumulation, then, it is essential to have a pervious stratum with an impervious or non-permeable cover to limit the upward movement of the oil and gas. This is a fundamental conception in the theory of accumulation, which states that in an inclined, porous stratum saturated with oil, gas, and water, the oil and gas, will tend to move up the dip until stopped by some obstruction, and that at such a point a pool will be formed. Methods by which this migration is stopped and a pool formed are described in the following sections.

Anticlines.—Strata which have been folded so that the beds dip away from the summit in at least two directions constitnte an anticline. If a porous layer saturated with oil, gas, and water, and overlain with an impervious layer, is warped into folds, the oil and gas will tend to rise to the highest points of the containing layer, *i.e.*, under the arch (anticline) (Fig. 1). Where

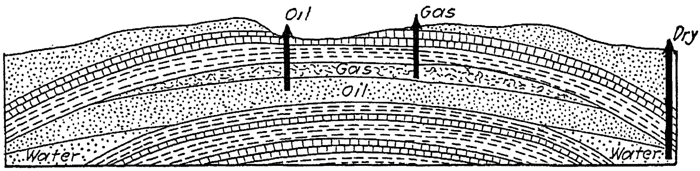


Fig. 1.—Anticline showing theoretical position of gas, oil, and water in sand of uniform character.

an accumulation takes place in an anticline the limbs or sides of which dip at low angles the oil and gas will tend to occupy a less thickness of the containing member and to spread out over a greater area than in a fold with more steeply dipping limbs. Conversely, steeply dipping limbs tend to cause a greater thickness

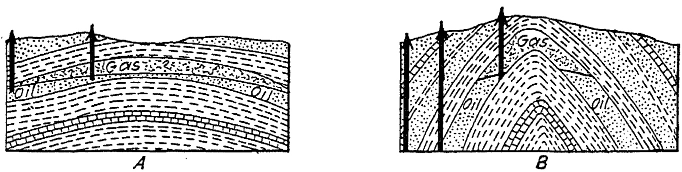


Fig. 2.—Anticlines showing (*A*) broad shallow accumulaton, with gentle dips and (*B*) deeper narrow accumulation with steeper folds.

of the sand to be saturated, the production to extend to a less horizontal distance down the limbs, and the depth of the producing sand below the surface to increase rapidly with distance from the crest of the fold (Fig. 2). That portion of a thin sand which lies near the crest of the fold may be unable to contain all the oil and gas so that these substances may extend farther

down the limb of the fold than would have been the case if the sand had been thicker.

Other things being equal, the more completely closed the anticline is by dips away from its crest in all directions, the greater are the chances of its trapping oil; and the larger the structure, the greater the amount of oil that will probably be trapped.

A discussion of the size of folds usually refers to their vertical rather than their horizontal dimensions, although the two are usually, but not always, closely related. The size may thus be spoken of as the amount of "closure," "reversal," or dip in the direction opposite to that of the regional. Thus in an area of west regional dip a fold which closed six ten-foot contours would

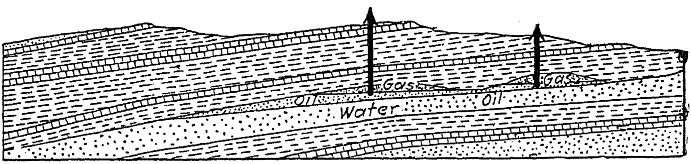


Fig. 3.—Accumulation caused by irregularities of upper surface of sand, in monoclinal dip.

have between 50 and 70 ft. of "closure," "reversal," or "east dip."

Domes.—Domes or quaquaversal folds are merely a special type of anticline more or less circular in plan.

Plunging Anticlines.—Plunging anticlines, often called "noses," are those which have no closure, whose axes pitch in one direction only. In such cases the oil and gas tend to migrate up to and then along the axis of the fold where, if further migration is stopped, a pool may be formed.

Monoclinal Dips.—Where the dip is all in one direction, as in the case of regional dip (see pp. 140–141), it is said to be monoclinal. Pools may occur in areas of monoclinal dips due to a thinning (Fig. 3), a tightening (decrease of porosity) (Fig. 4), or a break in the continuity of the containing sand (Fig. 5).

The line of obstruction must be nearly parallel to the strike of the beds, otherwise the oil and gas will move obliquely up the dip. There are absolutely no surface indications of such thinning or

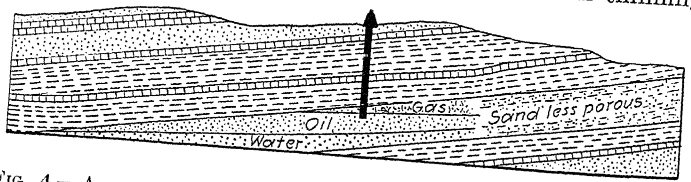


FIG. 4.—Accumulation of monoclinal dip, owing to tightening of sand.

tightening of the sand and no way of predicting, from surface conditions, the location of such a pool.

Terraces.—In a region of monoclinal dips, areas that are structurally flat, or notably less steep than the regional inclina-

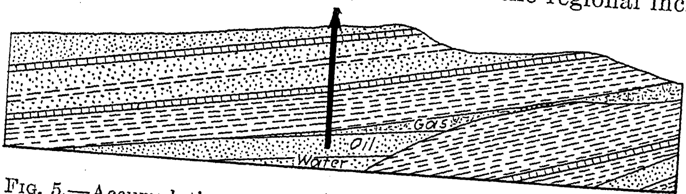


FIG. 5.—Accumulation on monoclinal dips caused by lensing of sand.

tion, are known as terraces (Fig. 6), or "arrested anticlines." At the point where a steeper dip changes to one that is more nearly flat, the movement of oil and gas may be checked and an

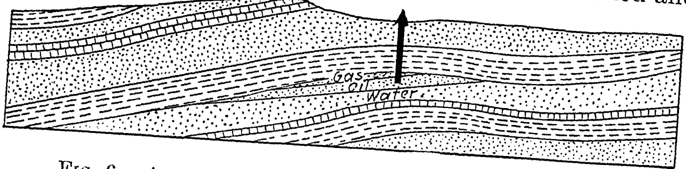


FIG. 6.—Accumulation on terrace or "arrested" anticline.

accumulation take place. Other things being equal, the more nearly flat the terrace and the wider it is, the greater the retarding effect.

Faults.—Where the oil and gas bearing beds are cut by faults, that is, by fractures along which movement has shifted the walls with respect to each other, a number of conditions are to be considered.

If the break is open (Fig. 7), the oil and gas, if present, will escape to the surface and be lost. If the break is tight, a condition which usually results where the impervious formation is shale and the stratigraphic throw does not exceed its thickness, the oil and gas will not escape, but one of a number of conditions may ensue: First, if the strata are dipping to the west, and the east side of the fault is the downthrow side (or *vice versa*), the pervious formation will, with certain exceptions, be blocked at the top for a vertical thickness equal to the throw of the fault (Fig. 8). This will be true unless the stratigraphic throw exceeds the thickness of the formation, in which case further migration will be completely obstructed (Fig. 9); or unless a second pervious member is brought opposite the first

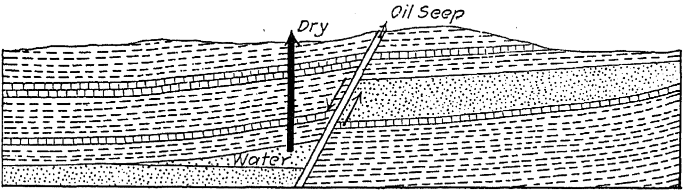


FIG. 7.—Loss of oil (seepage) along open fault.

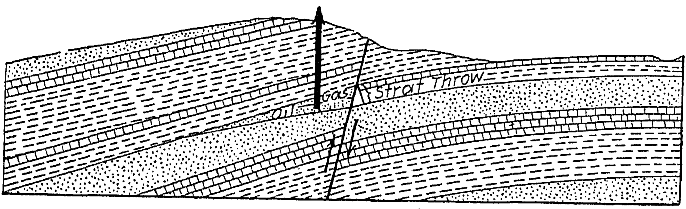


FIG. 8.—Partial obstruction of migration by fault, a case in which the stratigraphic throw is less than the thickness of the oil sand.

permitting the oil and gas to continue on their way (Fig. 10). Second, if the beds dip west, and the west side of the fault is the downthrow side, the migration will not be hindered (Fig. 11) unless the stratigraphic throw of the fault exceeds the thickness

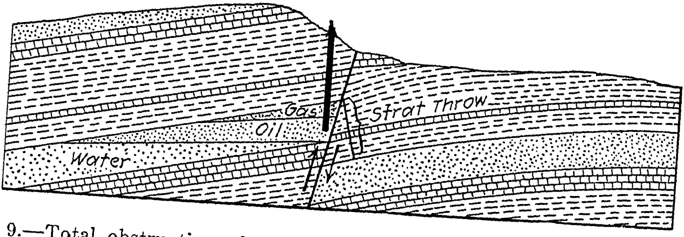


FIG. 9.—Total obstruction of migration by fault, a case in which the stratigraphic throw exceeds the thickness of the oil sand.

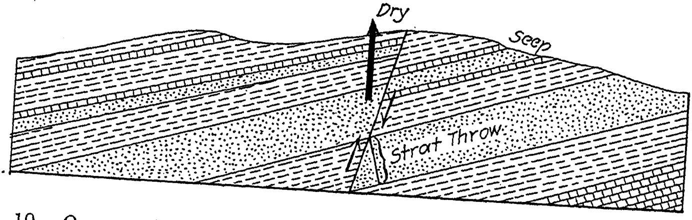


FIG. 10.—One pervious stratum faulted opposite another so that migration is not interrupted.

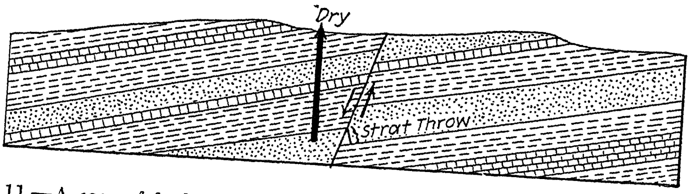


FIG. 11.—A case of faulting of oil sands in which migration is not obstructed.

of the pervious stratum (Fig. 12) or unless there has been a cementation of the sand along the fault plane.

It is also possible that the fault plane may be open part way but not entirely to the surface, in which case oil and gas may escape from a lower sand into an upper one (Fig. 13).

Faults of a few feet displacement may die out with depth and not effect deep-seated oil sands at all. Likewise the lower formations may be broken by faults which do not reach the surface. It is probably not possible, with our present knowledge, to make safe predictions regarding the increase or decrease of throw in specific cases with depth.

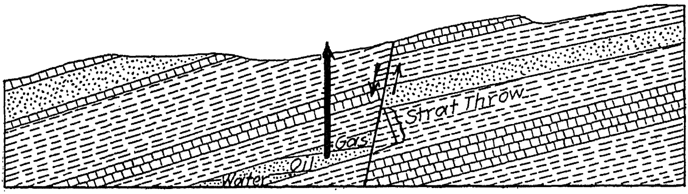


FIG. 12.—Migration entirely interrupted by faulting.

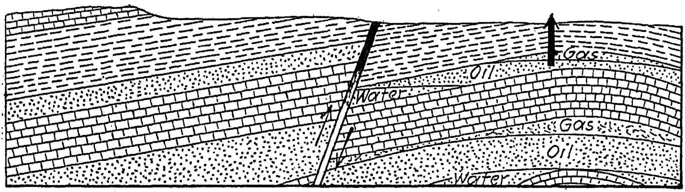


FIG. 13.—Oil escaping along an open fault from a lower to a higher sand.

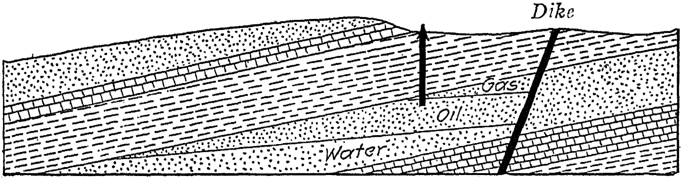


FIG. 14.—Accumulation caused by a dike.

Dikes.—Where the dipping oil sand is cut by a dike of impervious igneous rock, the oil may migrate up the dip to the barrier, and there be trapped (Fig. 14).

Beds Sealed Off by Asphalt.—Where an inclined oil sand outcrops at the surface, its oil content may slowly escape until

the accumulating asphaltic residue left during evaporation effectively seals off further loss. Other oil may then migrate up against the asphalt cap, or brea, and there be trapped (Fig. 15). Such oils are likely to be of low gravity.

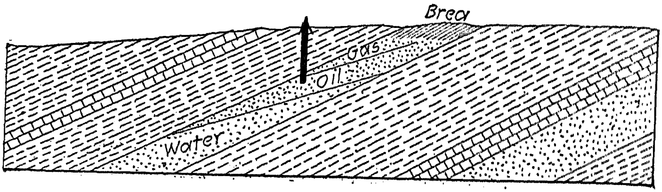


Fig. 15.—Oil accumulation caused by "sealing" off with asphaltic residue.

Angular Unconformity.—Where older inclined oil bearing beds have been truncated by erosion and then buried by later flat-lying strata, the oil, if not completely lost during the erosion

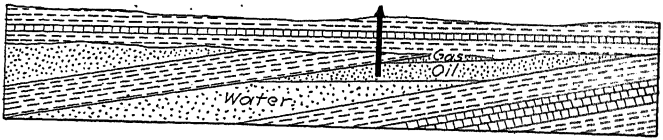


Fig. 16.—Oil trapped by angular unconformity.

interval, through seepage, might move up till it is trapped at the unconformity (Fig. 16). There would usually be no surface indication of such a condition, and the location of such a pool

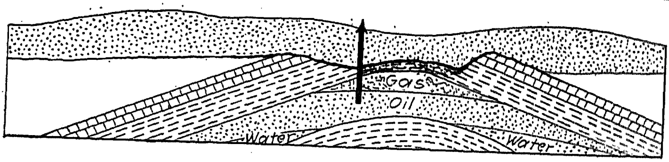


Fig. 17.—Anticline concealed beneath angular unconformity.

could seldom be foretold. In a similar manner anticlines may be buried beneath younger unfolded strata, and be absolutely inaccessible to surface study (Fig. 17).

Synclines.—In all the above cases, it was assumed that the beds were completely saturated. Where there is little or no water in the rocks, and consequently no hydrostatic pressure, the oil may accumulate in the lowest part of the trough or syncline (Fig. 18). If the rocks are partly filled, the oil may lie on either flank of the structure, just above the water line (Fig.

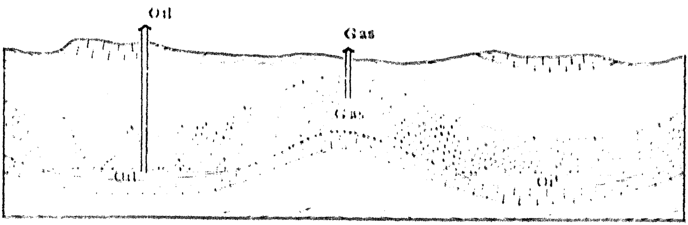


FIG. 18. Oil accumulation in synclines, in rocks that are not saturated with water.

19). Gas, if present, will, if possible, move to the crest of the anticline in all cases.

Effect of Sand Irregularities.—If sands were perfectly uniform in thickness and porosity, prospecting for oil and gas would be much simplified. Shallow water formations, such as true

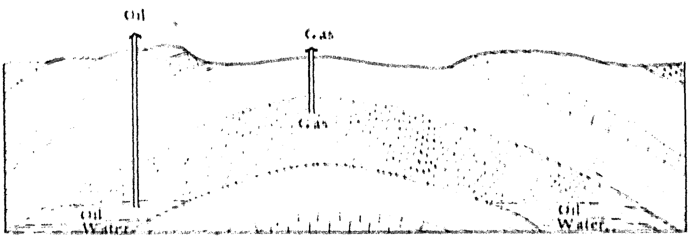


FIG. 19. Oil accumulation on flanks of anticline, in beds that are only partially saturated with water.

sands, are typified by abrupt and marked changes in the thickness and in the lithologic and structural characters of the strata. The effects of irregularities in sands may be considered to be of three types; those in which the sand lenses out entirely, those in which it loses its porosity, and those in which the porous sand continues but is of changing thickness.

Where the porous stratum ceases to exist, oil migration must stop and a pool may be formed (Fig. 5). The same condition results where the voids of the sand are filled with some foreign matter such as clay, in which case the sand is said to be "tight" (Fig. 4). Irregularities in the top of the sand may cause oil and gas to be trapped, only when this variation is so marked as to cause a terracing or reversal in the dip of the overlying formation (Fig. 3).

There has been no careful study as to the relative amount of variations in the top and bottom of sands, but the field evidence at hand indicates that there is very little difference, so that a sudden variation in the thickness of a sand may be due to an irregularity in the top, in the bottom, or, more likely, in each.

In going into new regions it is essential that the geologist learn as much of the underground conditions as he can by studying the logs of deep water wells; also by examining the prospective oil horizons at the nearest point of outcrop, to determine their thickness, character, probable depth, and rate and direction of lateral variations. There is little assurance, however, that these conditions will persist for any considerable distances from the outcrop. Only the drill will reveal the sand conditions.

In an area that is partly drilled up, it may be possible to determine certain general conditions of sand change, but frequently it is quite impossible in strictly wildcat (unproved) territory.

The geologist, then, in the field, is engaged largely in trying to locate structural conditions, such as anticlines, terraces, etc., favorable to the accumulation of oil and gas. In the following chapters, the authors attempt to describe the instruments employed in mapping structures, their uses and limitations, the procedure in the field, and the making of the finished map. No effort is made to discuss subsurface conditions, or to outline the considerations involved in the location of holes, not because these features are unimportant, but because they have already received detailed consideration in other publications.

CHAPTER I

INSTRUMENTS

LEVEL VIALS

The level vial or bubble-tube is filled with some liquid of low viscosity and freezing point (usually ether, alcohol, or a mixture of the two) containing a bubble which commonly consists of the vapor of the substance with which the tube is filled. As both of these substances, but more especially the ether, expand on being heated and contract on cooling, the bubble is apt to be too small in summer and too large in winter. The disadvantages of this are, that in cases of extreme heat the bubble may disappear entirely and can be brought back only by the application of a wet cloth, and that a bubble's sensitiveness varies somewhat with its length, a long bubble settling more quickly and accurately than a short one. For this reason precision instruments are usually equipped with level tubes such that the amount of liquid can be regulated, but the ordinary small alidade does not have such an adjustment. Vials which are adjustable show by special markings the most desirable bubble length.

The bubble-tube is graduated into divisions of about two millimeters, and preferably upon the glass itself. The upper portion of the inner surface of the tube of a level vial or spirit level is ground longitudinally to a predetermined curvature, the radius of which determines the sensitiveness of the bubble. For a given change in the position of the tube, the bubble must move through a definite arc, the length of which, and hence the sensitiveness of the bubble, varies directly with the radius of curvature and indirectly with its curvature.

The sensitiveness of a bubble is usually expressed either by the length of the radius of curvature, or, what amounts to the

same thing if the spacing of the divisions is known, by the number of seconds of arc that correspond to one bubble-tube division. The sensitiveness of the level vials furnished with the small alidades commonly used in oil geology varies from about 90″ to 40″.

If the striding level is in adjustment, an error of one vial division in leveling will, at a horizontal distance of 1000 ft., result in an error in the vertical distance of 0.436 ft. with a vial of 90″ sensitiveness, 0.291 ft. with one of 60″ sensitiveness, and 0.194 ft. with one of 40″ sensitiveness. If the vial is one division out of adjustment, *i.e.*, when it has been carefully leveled and then reversed a difference of one division is found in the readings, the resulting error in vertical distance will, however, be the equivalent of only one-half of a bubble division.

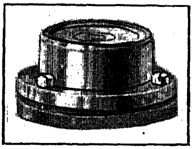


FIG. 20.—The bull's-eye level.

As a matter of accuracy and convenience the sensitiveness of a bubble should be adapted to the use to which it is to be put, *i.e.*, a telescope of high magnification should have a very sensitive bubble, one of long radius of curvature, while one of low power should have a bubble that is much less sensitive, one of shorter radius.

The instrument makers complain that the public is inclined to demand a bubble that is more sensitive than is warranted by the character of the instrument upon which it is to be used. For rapidity of work it is best that the sensitiveness of a bubble be such as to just permit of the detection of the least unallowable error in the line of sight.

The bull's-eye level (Fig. 20 and Pl. IV) has now quite commonly superceded bubble-tubes as a means of leveling the base of the small alidade, or the plane table on which it rests. In this the inner surface of the glass is part of a sphere of long radius. By means of such a level the base can be more quickly leveled as the bubble shows directly the highest side. The radius of curvature is only moderately long since great accuracy in leveling the base is unnecessary. Time is often needlessly

wasted by the instrument man in trying, unknowingly, to obtain an unwarranted degree of accuracy in base leveling. If the table top has a slope of 2°, normal to the line of sight, the error in measuring vertical distance will be only 0.06 per cent. It requires a slope greater than 8° to give an error of 1 per cent. (See also pp. 63–64.)

THE COMPASS

History of the Compass.—It is not known where and when the principles of the compass were first discovered. The fact that the earth is surrounded by a magnetic field such that a magnetized needle tends to assume an approximately north and south direction was known to the Chinese about a thousand years before the beginning of the Christian Era. As early as the third and fourth centuries they used floating and mounted magnetized needles for navigation purposes.

The discovery of magnetic declination by Columbus in 1492 and of magnetic inclination by Hartmann in 1544 have added greatly to the usefulness of the compass needle. More recent developments have made possible such refinement in construction and in methods of use that the compass, with its clinometer attachment, is now indispensible in geologic field work.

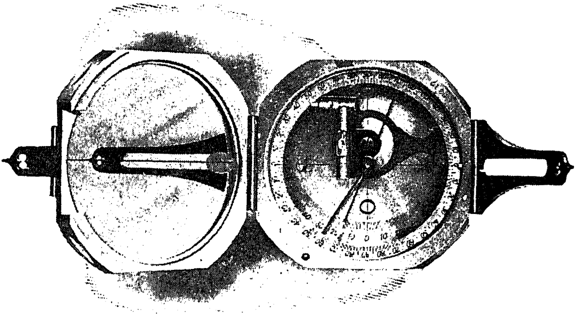
Description of the Compass.—The essential parts of a geologist's compass are a well mounted, balanced, and magnetized needle, preferably not less than 2 in. in length; an automatic stop to raise the needle from the pivot when not in use; a circular scale graduated to degrees and adjustable for declination; a clinometer attachment with suitable scale markings for reading the dip of rock strata and the slope of surfaces; and a straight edge, preferably two, one along the top and one along the bottom, which can be used in connection with the clinometer. Other attachments such as a mirror, a peepsight, etc., are often found to be convenient.

The needle must be sensitive and must constantly assume, when free to do so, the direction of the magnetic meridian. The first condition is brought about by attaching to the cen-

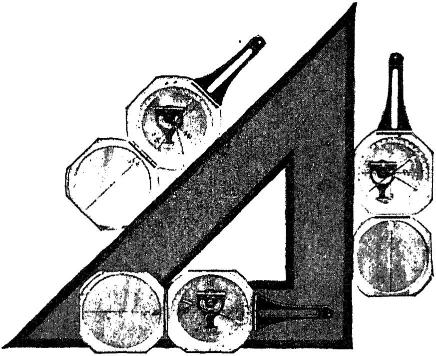
ter of the needle an inverted agate (jewel) cup such as will receive and turn freely upon a pivot made of the hardest steel and ground to a smooth, round sharp point. The second is satisfied by making the needle of sheer steel and strongly magnetizing it.

The north-seeking end of the needle is generally bright and may be marked with an arrow or the letter *N*, while the south-seeking end is dull colored and, in the northern hemisphere, weighted with a wrapping of small wire which can be slipped along the needle to counteract its tendency to assume an inclined position, *i.e.*, parallel to the magnetic lines of force. Most compasses are of the *direct reading* type, *i.e.*, when the north end of the compass is pointed in the desired position and the direction of the north-seeking end of the needle read (and *vice versa*) the correct magnetic direction is obtained. This is brought about by interchanging the east and west markings (E. and W.) on the compass and is due to the fact that the compass box and not the needle is rotated and pointed. Thus if the north end of the compass is pointed in a northwest direction, the north-seeking end of the needle will lie on the east side of the north mark so that, unless the east and west marks have been interchanged, it will read northeast instead of northwest.

The compass best adapted to geologic work is known as the "Brunton pocket transit" (Pl. I) after its inventor, D. W. Brunton. Owing to patent rights (now expired) the cost of the Brunton compass has been somewhat excessive. Nevertheless it is probably used by more professional men than all other types of compasses together. It consists of a delicate needle about 2⅛ in. long with a jeweled socket at the center, and is provided with an automatic stop which lifts the needle from the pivot as the compass is closed. A clinometer with a sensitive spirit level is attached to the inside of the compass box and its position controlled by a small flat lever on the outside of the bottom. The clinometer arc is graduated to degrees but can be read by vernier to five minutes. The compass box carries a sighting point and a brass peepsight which can be very conveniently used

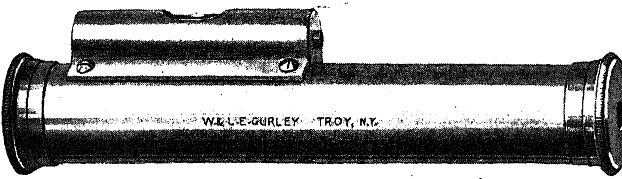


A

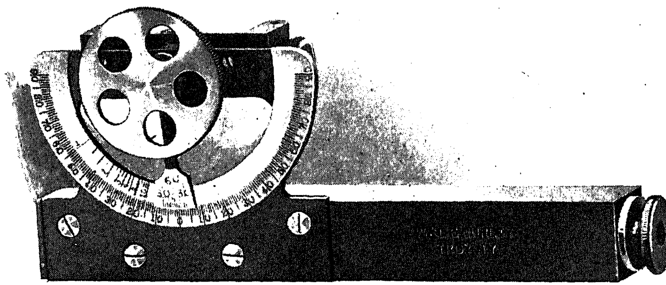


B

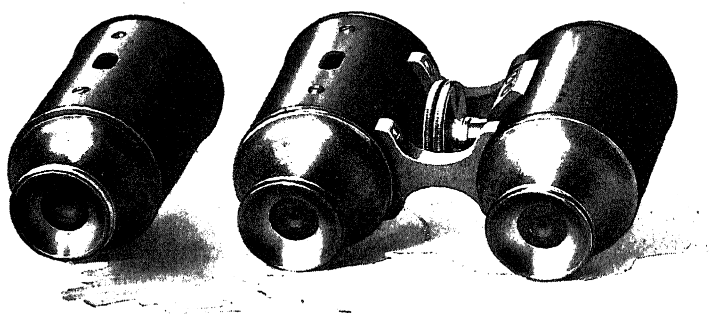
The Brunton Compass. (*After Ainsworth.*)



A.—Locke hand level. (*After Gurley.*)



B.—Abney hand level and clinometer. (*After Gurley.*)



C.—Monocular and binocular hand levels. (*After Gurley.*)

in connection with the mirror and center line on the inside of the cover for securing various kinds of sights. The compass ring and variation plate is graduated to degrees in quadrants and can be easily shifted by means of a pinion with a slotted head to correct for local declination. The case is a solid aluminum casting 2¾ by 2¾ by 1¼ in. in size and weighs 8 ounces.

Care of the Compass.—A compass should be given reasonable care in order that it may continue to give good service. The main thing to guard against is sudden shocks, for if the needle is on the pivot the latter may be broken or dulled or the agate bearing may be loosened. Besides this there is always the danger of changing the magnetic axis of the needle, especially of a needle which has been recently magnetized. Most instruments are provided with stops by means of which the jewel bearing can be lifted from the pivot when the needle is not in use. This should always be done.

It is sometimes desirable to remove the cover glass to make adjustments but this should not be done unless absolutely necessary as the manufacturer usually cements the cover glass in place to exclude moisture which might rust the pivot. Needles may be remagnetized and reweighted, jewels cleaned and pivots brightened and sharpened when necessary, but unless immediate attention is demanded by the exigency of the case, those conditions would best be corrected by the maker.

Use of the Compass.—The simple compass is used to determine direction where a high degree of accuracy is not required. This method may be advantageous over other methods in that the compass costs less than other instruments used for this purpose and is more simple and rapid of manipulation. The geologist uses it chiefly to determine the approximate direction of points on a traverse, and the directions of the dip and strike of beds, faults, etc. In mapping it is an essential part of the instrument equipment. By its use the plane table can be oriented without the use of backsights, part of the otherwise necessary instrument stations being eliminated, and the rapidity of the work increased. (See also pp. 76–77, and 84–85.)

The needle can be brought to rest by catching it with the stop at the middle point of its swing and releasing it quickly. It will then vibrate but little and will soon stop. Readings can also be taken by the average method, with the needle still swinging, as is done with a sensitive balance.

In oil geology field work the clinometer is an essential part of the hand compass. This attachment, which most compasses have, is used to determine the dip of planes, or the slope of surfaces, and is utilized nearly as often as is the needle. Ordinarily clinometers are graduated to read in degrees but may be graduated to read in percentage grade or in any other desired ratio. Usually the angle and direction of dip or slope is all that is desired, but when considered with the distance between given points, these values can be used to determine, by the vertical angle method, the relative elevation of the two stations, exactly as is done with the alidade or military sketching board. With the clinometer set at zero, the compass may be used directly as a hand level.

HAND LEVELS

Under this heading are included all those instruments which are held by the hands alone during observations and by which the relative elevation of two points is determined. They consist essentially of a spirit level so arranged, usually by the aid of a prism or mirror, that the bubble and zero mark, or index, are in the field of view when the point under observation is being sighted upon. Mirrors are lighter, cheaper, and less easily broken than glass prisms and in many cases are quite satisfactory, but metallic surfaces are subject to tarnish and disintegration whereas prisms are sufficiently light and strong, and never lose their reflective power irrespective of climatic conditions. All metallic portions of the level are non-magnetic and do not influence the compass needle. The hand level is made in forms to be used with either one or both eyes, with or without magnification.

Locke Hand Level.—This popular type of hand level was invented by Prof. John Locke, M. D., an American scientist, in 1850. As now manufactured by different firms, some variations in construction are found. The most common type of this instrument consists of a short non-magnetic metallic tube or barrel about 5 in. long and ¾ in. in diameter, upon the top of which, in the position of maximum illumination, is mounted a small spirit level (Pl. II, A). A cross-wire is fastened in a horizontal position to a little movable frame under the level tube and is adjusted by changing the position of this frame by means of two small screws, one at each end of the level-case. Both ends of the barrel are closed by plain glass disks to exclude dust.

Under the bubble-tube and occupying one vertical half of the barrel is a prism, or mirror, so inclined that the image of the bubble is reflected to the small opening in the eyepiece. The prism, a triangular piece of glass about two-tenths of an inch in thickness, is so placed that the front or eyepiece edge is vertical, the top horizontal, and the back and lower edge inclined at 45° towards the eye end of the tube. Light from the bubble strikes the top of the prism with normal incidence, enters, strikes the inclined edge at an angle of 45°, and is totally reflected back through the prism and out towards the eyepiece because the angle of incidence on the inclined edge exceeds the critical angle of the glass. The result is that the bubble-tube appears to stand in a vertical position alongside the field of view which is seen through the other half of the barrel. When held in a horizontal position the bubble appears to be bisected by the horizontal wire, and the point in the field of view opposite this mark is on a level with the eye.

Some instruments have a draw-tube, ½ to 2 in. long, containing the segment of either a plano-convex or a biconvex lens which so changes the light from the level bubble and the cross-wire that the eye can be conveniently focused upon them in one-half of the field of view and upon the landscape in the other at the same time.

Square Hand Level.—A square hand level has become quite popular among geologists (Fig. 21). In this the bubble-tube and the eyepiece are similar to those in the Locke level, but the horizontal wire and the reflector are part of a slide which slips into the open end of a square barrel to the position of adjustment under the bubble-tube. The horizontal wire is strengthened by being constructed of a metal sheet, the cross-section of which appears as a wire. The reflector, a narrow prismoid of polished metal, appears in a vertical position across the center of the field so that the intersection of the horizontal wire with the view can be seen on both sides of the bubble. The mirror is narrowed at each end so as to obstruct less of the view. This instrument is square in cross-section and so can be used as a contact level, but it owes its popularity in the main to the fact that it is smaller and more easily carried than the round models. It is objectionable in that, as usually constructed, it cannot be focused or readily adjusted. The absence of an adjustable lens causes the horizontal wire to appear large and to blurr when a distant point is viewed. The level is adjusted by wedging up one end of the bubble-case or by moving the mirror carriage in or out as required. The slots which carry the supports of this slide may be filed deeper and the carriage pushed farther in, but it is unsafe to use the level with the carriage in any position other than inserted as far as it will go.

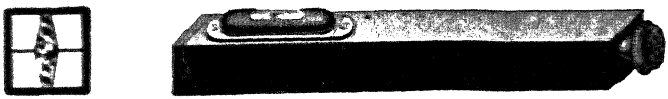


Fig. 21.—Square hand level.

Abney Hand Level and Clinometer.—This instrument was designed by Capt. Abney of the British Army. It is an adaptation of the Locke level to the reading of angles and differs from it in that the bubble-tube and a vernier are attached to a movable arm in such a manner that the bubble is always visible (**Pl. II, B**).

To determine the vertical angle or slope, bring the line of

sight to bear upon the station, the relative elevation of which is wanted, or parallel to the slope to be measured, and turn the arm with the bubble and vernier until the bubble is bisected by the index, in which position the scale will show the angle. Angles up to 60° or 90° may be read in degrees and minutes to the nearest 5 or 10 minutes or in percentage for slopes between 1 in 1 and 1 in 10.

Gurley Monocular and Binocular Hand Levels.—These instruments combine the properties of the telescope and the hand level. The following description is copied from the Gurley catalog.

"The monocular hand level (Pl. II, C) consists of a tube to which are fitted the lenses of a single opera-glass, containing in addition a reflecting prism, a cross-wire, and a small spirit level, the last being shown in the open part of the tube.

"The eye-lens, as indicated in the cut, is made of two separate pieces, the larger one being the usual concave eye-lens of the opera-glass and the smaller one a segment of a plano-convex lens, having its focus in a cross-wire under the level vial and above the reflecting prism.

"The observer holds the tube horizontal with the level opening uppermost, and observes the object to which the instrument is directed and the position of the level bubble with reference to the cross-wire on the under side of the level vial.

"When the hand level is held truly horizontal the cross-wire will bisect the bubble, and will also determine the level of any object seen through the telescope: thus securing to the observer a clear view of the object, magnified also by the telescope.

"The binocular hand level (Pl. II, C) consists of two tubes, that on the right enclosing the usual lenses of the opera-glass, while the tube on the left contains only the prism, level vial, and cross-wire of the instrument just described.

"This instrument is used like the ordinary opera-glass, the level being above, as shown in the cut.

"The hand level is adjusted by sliding the prism tube back and forth until the line given is the same as that given by a Y-level.

"The prism in the tube can be reached by removing the cap from the

closed end of the tube, and it is clamped by a small screw on the lower side."

Bausch & Lomb Prismatic Binocular Hand Level.—Most instrument makers are offering very good prismatic binoculars but Bausch & Lomb have so added to the general design that the instrument can be used for leveling and stadia work.

The prismatic binoculars embrace the stereoscopic principle and were introduced by Dr. Ernest Abbe of the Zeiss works in 1893. By means of a prism (Fig. 22) the natural inter-ocular distance and the consequent stereoscopic effect are nearly doubled. They likewise permit of a large field of view, a high telescopic power, and at the same time a compactness which is not found in instruments of other types. The following description is quoted from the catalog of the makers.

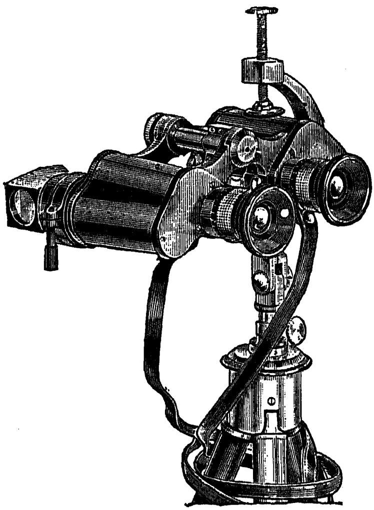


FIG. 22.—Bausch & Lomb prismatic binocular hand level.

"In one monocular is placed a glass diaphragm with a Maltese cross, marking the usual stadia interval of 1:100 in both the vertical and the horizontal planes.

"The bubble-tube is mounted on the underside of the hinge-bar in a position where it may be conveniently viewed through the small lens that is set in the eye-cup, as shown in the illustration. The small lens may be adjusted to position by revolving the eye-cup. Each eyepiece is provided with a diotropic scale so that the inequalities of vision can be rectified and the interpupilary distances can be quickly set to suit any observer.

"The bubble and the field of view do not appear simultaneously as in the Locke hand level but much as in the Wagner-Tesdorpf model

and in a manner quite as effective, permitting an unobstructed and undivided field of the very highest optical qualifications.

"This binocular is usually supplied with 8-power optics, which is about as high a magnification as can be held steadily in the hand."

Care, Testing, and Use of Hand Levels.—Hand levels are strongly made but should be given reasonable care as they contain glass parts and are subject to adjustment. They should be frequently tested and adjusted to the accuracy of their legibility. In all cases the bubble-tube is cemented in position and the adjustment made by moving the cross-wire, the mirror, or the bubble-tube case. The position of the cross-wire in the ordinary Locke level is changed by means of the screws at the end of the level case, one being screwed in and the other out so that the slide upon which the cross-wire is mounted is held firmly between them. In the case of the square level, one end of the bubble-tube case is shimmed up or the slide which carries the mirror and cross-wire in the end of the tube is moved in or out as may be required. To adjust the Abney level and the clinometer of the Brunton compass, loosen the screw which holds the level case and the vernier arm together and correct the relative positions of the two. This is somewhat difficult as the tightening of the screw may change the relative positions.

There are many methods by which the accuracy can be tested; some of the more convenient ones are described in the following paragraphs.

(*a*) If the alidade is at hand it will be found convenient to level it carefully and to note the points at which the middle horizontal wire cuts some distant object and one near by. The hand level can then be held firmly against the nearer object at the point noted, sighted upon the farther point, and adjusted until the horizontal wire appears to bisect the bubble.

(*b*) One may choose two trees which are on about the same level and about 100 yds. apart. The level is rested against one of the trees at a point easily recognized from the other one, sighted upon the latter, and the point of intersection of the cross-wire on the tree when bisecting the bubble noted. The

observer then goes to the second tree, places the level at the point of intersection and sights upon the first point. The bubble is adjusted to one-half the apparent error and the operation repeated until the adjustment is satisfactory.

(*c*) Contact instruments, such as the Brunton compass, are more easily corrected while being held in contact with a horizontal surface. This may not be safely done with levels of the Locke type because their horizontal line of sight is not necessarily parallel to the axis of the barrel.

In oil work the hand level is used for much longer observations than in other branches of engineering. Observations of a half mile or a mile in length are common, the greater the distance at which it can be used the better. The best simple hand level for general use is one which has a draw-tube with lens segment, a reflecting prism, a small but distinct cross-wire easily adjusted, a small hole (about one millimeter in diameter) in the eye end to decrease the parallax, and a fairly sensitive bubble, the whole so constructed as to hold its adjustment.

Hand levels are small but valuable instruments for quick approximations in both reconnaissance and detailed work; also for more accurate work such as determining the interval between two outcrops, for carrying an elevation up a hill or through the trees to a point where the rod can be read from the instrument, for carrying the position of a bed across an area of no outcrops, etc.

It is sometimes convenient to use the hand level as a clinometer to the extent of determining in which of two directions a given bed or stratum is dipping. By holding the level a short arm's length from the eye, its axis normal to the line of sight, it may be held with its top parallel to the dipping bed the direction of dip of which is shown by the position of the bubble. This method assumes that the line of sight of the level (as defined by the image of the cross-wire and the center of the eyepiece opening), is parallel to the top, which may not be true. The Brunton compass is commonly and correctly used in this way.

A serious objection to the use of the non-telescopic hand level

is that since it has no telescopic line of sight, a slight movement of the eye of the observer will cause a considerable change in the position of the intersection of the cross-wire with the field of view (parallax). The telescopic varieties have such a line of sight and this apparent movement of the cross-wire is avoided when the instrument is correctly focused. (See also pp. 111–113.)

BAROMETERS

History.—The invention of the mercurial barometer, usually attributed to Torricelli in 1643, was a result of the study of the supporting power of a vacuum. This investigation by Galileo led his pupil, Torricelli, to discover that if a glass tube is closed at the lower end, filled with mercury, and then quickly inverted in a dish of mercury so that no air is permitted to enter the tube, the height of the mercury column in the tube varies with the atmospheric condition or pressure. This is the fundamental principle of all mercurial barometers. The fact that the atmospheric pressure varies with the elevation above sea level was first conceived by Blaise Pascal and demonstrated, at his request, by Périer in 1648.

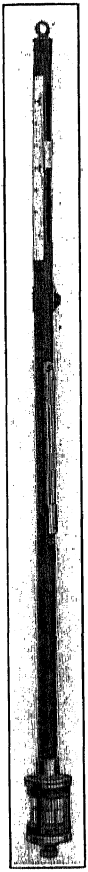


Fig. 23.—Mercurial barometer. (*After Jameson.*)

MERCURIAL BAROMETER

The mercurial barometer (Fig. 23) consists essentially of a glass tube which has been sealed at one end filled with pure mercury, and inverted into a dish of mercury; together with a scale graduated into inches to measure the height of the mercury column in the tube above that in the dish or cistern. Gravity tends to draw the mercury from the tube while the pressure of the atmosphere upon the surface of the mercury in the dish or cistern tends to counteract the force of gravity, the mercury column rising to a height such that its weight is equal to

the atmospheric pressure on an equivalent area in the cistern. Thus a balance is established and the height of the mercury column varies with the air pressure.

The transportation of a mercurial barometer, approximately 34 in. in length, from place to place as might be required by geologic work is neither practicable nor necessary, the aneroid barometer being used instead. Further description of the mercurial barometer is therefore omitted.

ANEROID BAROMETER

History and Construction

"In 1798 M. Comté, Professor of Aërostatics in a school at Meudon near Paris invented a 'watch-like, metallic airtight vacuum case, the lid of which sustained by internal springs, rises and falls under variable pressures.' This undoubtedly was the first 'aneroid' (Greek compound 'without fluid') barometer, and was made for the reason that in his balloon ascents he found the mercury barometer suffered greatly from violent oscillations."[1]

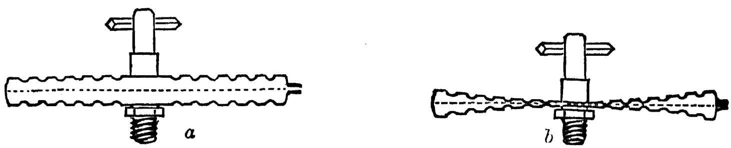
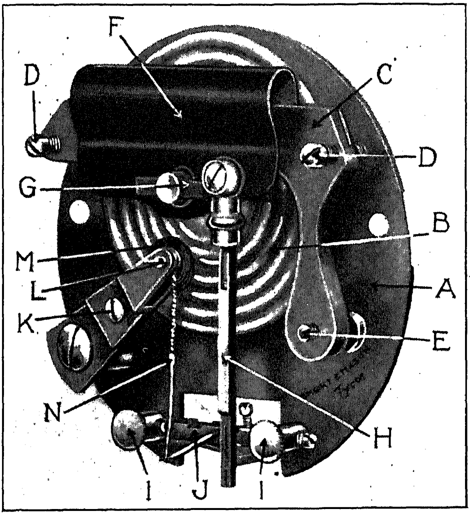


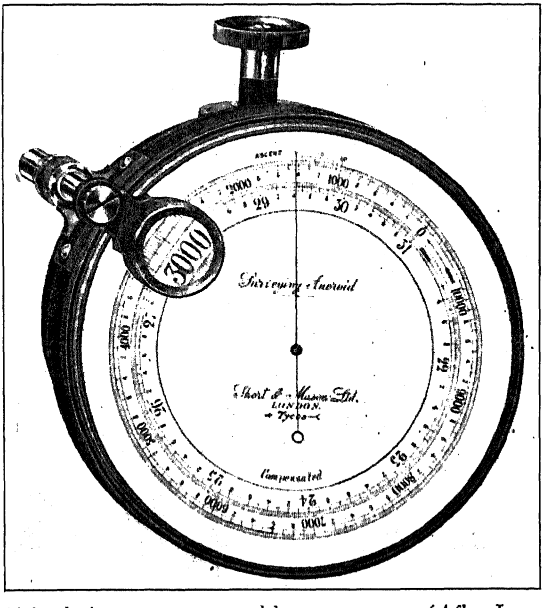
Fig. 24.—Barometer chamber (*a*) before exhaustion; (*b*) after exhaustion. (*After Jameson.*)

The first serviceable form of the aneroid was made by Vidi in 1848 and consisted of a low cylindrical metal box hermetically sealed after the exhaustion of the air (Fig. 24). The top and bottom were corrugated to increase their flexibility and held apart by an external spring. The point of equilibrium between the vacuum box and the spring was very readily effected by even slight changes in the atmospheric pressure upon the ends of the vacuum chamber. By a series of mechanisms, the motion was

[1] Jameson, P. R., The barometer as the foot rule of the air, p. 6, 1915, published by the Taylor Instrument Co.



A.—Internal mechanism of modern altitude barometer.



.—Altitude barometer as used by surveyors. (*Af'er Jameson.*)

conveyed in a highly magnified form to a dial where it could be read.

The general principle of all aneroids is the same. The one most commonly used today differs from the Vidi in that a laminated spring has been substituted for a spiral one.

A (Pl. III, A) is the base plate upon which the parts are mounted.

B is the vacuum box of german silver, the corrugated ends of which have a thickness of about 0.004 of an inch. The center of the lower end is fastened to the base plate by means of a screw and nut, and the top to the pillar through which the bar *G* passes. The ends are held apart by means of the spring *F*.

C is the bridge which spans the vacuum chamber *B* and holds the spring *F*.

D indicates the positions of two adjustment screws by means of which the bridge *C* is either raised or lowered, regulating the tension on the chamber *B*.

E is another adjustment screw by means of which the bridge *C* can be raised or lowered. The other end of this screw is to be seen in the back of all aneroids. This is the screw that is used in making most adjustments.

F is a steel spring one edge of which is held firmly in a slot in the bridge while the other presses firmly against the knife-edge of an angular steel rod *G* which passes through a pillar attached to the top of the vacuum chamber.

The bar *H*, compensated for temperature, is attached to the spring *F*, and at the outer end greatly magnifies the movement.

I marks the position of two supports or pillars fitted to plate *A*.

J is a bar or regulator, set between, and working on, steel points or pivots passing through the supports *I* and *I*.

At the outer end of the bar *H* is attached a small bar which extends down and is attached to the regulator. *J* by means of a short arm parallel to *H*. A vertical arm longer than the last, is also attached to the regulator *J* and to the end of the chain *N*, thus magnifying the motion of the outer end of the bar *H*.

K is an arm or cock to hold L and M.

L is the pin or arbor passing through the end of cock K.

M is a hairspring fitted to the pin L. Its duty is to move the index in a direction opposite to that caused by pulling the chain N, thus keeping the system taut and preventing any lost motion.

N is a steel chain, one end of which is fastened to the upper end of the vertical arm attached to the regulator J, the other passes around, and is fastened to a small wheel on the pin L, to which the indicator hand is fitted.

Thus an increase in the atmospheric pressure presses inward the ends of the vacuum chamber B. Because the lower end is attached to the base plate A, the motion is all taken up by the top which depresses the spring F and the bar H, rotating the bar J, and increasing the tension on the chain N, which in turn causes the index hand to move around the dial to the right indicating the new pressure. If the air pressure decreases, the spring and bars move in the opposite direction lessening the tension on the chain and permitting the hair spring M to move the index in the reverse direction.

Other types of aneroids are made, such as the Bourdon and the Goldsmith, but these are not adapted to the purposes of the geologist, and it is believed are not used in geologic work in the oil fields. They differ mainly in the number of vacuum boxes and in the transmission of the motion to the indicator.

Because of slight variations in the composition, construction, and tempering, the elasticities of the top of the vacuum box and of the springs are slightly different in each instrument. It has been generally considered essential that the graduations of the dial of each instrument be located by actual trial. This was done by placing each barometer in an air tight chamber and subjecting it to various air pressures, the values of which were determined by the use of a standard barometer. A number of positions of the pointer at known pressures having been determined the remaining divisions were laid off by interpolation. The ordinary aneroid is not so constructed, the dial being a standard printed pattern to which the mechanism of the barometer is adjusted as a

watch is adjusted to keep correct time. This method has been found to be accurate, practical, and much cheaper than the calibration and marking of the dial of each instrument separately. It is assumed that the elasticities of the springs are constant in the positions through which they move so that the amount of movement of the springs and the corresponding arc passed over by the indicator are in all positions the same for a given change in pressure. Thus the pressure scale marked in inches is equally spaced while the scale of feet is unevenly divided since the pressure change is not constant for each unit change of elevation, but is uniformly progressive (Pl. III, B).

The so-called surveying aneroids, such as are used in geologic field work, are graduated to show both inches of mercury and the equivalent pressure changes in feet, the positions of the latter markings being computed from the former by Airey's formula (see table VII, Appendix).

Under proper conditions the reading of pressure in feet of elevation is as accurate as the reading in inches of mercury, numerous text books to the contrary notwithstanding, and is very much more convenient as it saves many computations.

In order that a standard relation between height in feet and barometric inches might be obtained, Sir George Biddell Airey found it essential to assume a point at which the two scales coincide, and desirable that the zero point of the altitude scale should correspond to such a pressure as would seldom, if ever, be exceeded, so that the pointer would always be on the scale and negative readings avoided. For this he chose the 31-in. point, which is still generally accepted for this purpose and so indicated by the scales on the dials.

Inasmuch as the zero-foot point of the altitude scale is not at sea level, about 30 in., but at 31 in. (890 ft. below sea level), and as the atmospheric pressure is dependent in part upon conditions other than elevation, the aneroid is not to be regarded as an instrument for determining the elevation of a point as referred to sea level, but only for *the determination of the relative elevation of two points*, an observation on each of which must be

taken. The actual elevation of a point is obtained by comparing it with a point of known elevation.

It would be convenient if the scale could be movable so that in starting it could be set at zero or at the correct elevation; direct readings of differences of elevation as referred to sea level might then be taken. The public has requested such an instrument and the manufacturers have responded. Obviously such readings are inaccurate, for the change in atmospheric pressure is not constant for each unit change of elevation, but is uniformly progressive. A movement of the pointer over the space on the dial between 30 and 31 in. is equivalent to an altitude change of 890 ft., while a movement between 17 and 18 in. is equivalent to an altitude change of 1,580 ft.[1] All of the more accurate types of the aneroid have fixed scales.

Aneroid barometers are made in various sizes, their diameters ranging from about 2 to 5 in. The spacing of the divisions on the dial and the consequent legibility increases with the diameter and decreases with the scale range. The aneroid most commonly used in mapping the low folds of the Mid-Continent Field is the 3-in. size. The outer limit of the scale circle has a diameter of approximately 2⅝ in., and reads up to 6,000 ft., 31 to 24.87 in. of mercury. The smallest division on the main scale is either 10 or 20 ft., but may be read by means of a vernier to either 1 or 2 ft. These, when in adjustment, record the air pressure with sufficient accuracy and are more convenient to carry than the 5-in. size.

An aneroid made to read intervals of less than 10 ft. is usually supplied with a magnifying glass so attached that its relation to the scale will be constant and a possible chance for error avoided. After one has become fully accustomed to the instrument, he usually finds that the unaided eye is sufficient and the glass is removed, because it is rather bothersome in replacing the instrument in its case.

All aneroids of this type show through a small hole in the back

[1] Jameson, P. R., The barometer as the foot rule of the air, p. 13, 1915, published by the Taylor Instrument Co.

an adjustment screw which bears upon one end of the vacuum box. By turning this screw the pointer can be made to move over the scale until it indicates the proper elevation or agrees with a standard barometer at that point, but it does not follow that this should be done even though the discrepancy be large. The spacing of the graduations cannot be changed.

Variations in the Instruments

(*a*) The movable parts of an aneroid are more or less in constant motion due to the jars of transportation and the changes in the atmospheric pressure. A wearing away of the points in contact results in a slight relaxation of the springs by which such points are kept in contact, and hence in a gradual decrease in the pressure which they exert.

(*b*) The elasticity of the springs decreases with use and with time.

(*c*) The friction of the parts varies with their cleanness.

(*d*) Rust increases friction and irregularities.

(*e*) Because of the weight of the parts, the reading of an aneroid varies with the position in which it is held. Three 3-in. instruments, reading by vernier to 2 ft., showed average variations of 12, 25, and 35, ft. respectively when read in a horizontal position, face upward, and when read in a vertical position, stem upward. A 2½-in. aneroid reading to 10 ft., showed a change of 40 ft. under similar conditions.

(*f*) The scale may be correct only for certain pressures. Not uncommonly a barometer will read correctly only for points between certain limits.

(*g*) The reading of an aneroid is somewhat dependent upon the temperature because of the expansion or contraction of its metal parts, and of the air. Some claim that because of the incomplete exhaustion of the vacuum box, no temperature correction is necessary. Many barometers are marked "compensated," but the value of this correction is questionable. Perhaps one would be nearer the truth if he assumed that the

error of an aneroid due to temperature changes of its parts is a small one and may be safely neglected in ordinary field work.

All of these factors tend to change the reading of the index. They are compensated for in part in the construction, eliminated in part by proper use, and corrected in part by the adjustments provided. When one considers the great magnification of the movement of the top of the vacuum box as shown by the pointer, he can appreciate the delicacy of the aneroid barometer and understand how even slight variations may affect the reading materially.

Variations in the Atmosphere

The great difficulty experienced in the use of the aneroid barometer is due to atmospheric changes other than those which are the direct result of changes of elevation. They are the result of changes in temperature and humidity and of the action of the wind and the influence of topography.

Causes of Change in Atmospheric Pressure.—*Temperature.* As shown by the laws of Charles and Gay-Lussac, the volume of the air increases with its temperature, the pressure being constant.

Where, t = centigrade temperature,
T = absolute temperature = $t + 273$,
a = a constant, which for air is $1/273$,
P = pressure to be determined,
P_0 = pressure at 0°C.,
V = volume to be found,
V_0 = volume at 0°C.,

$$\text{then, } P = P_0 + atP_0 = \text{volume constant,}$$
$$= P_0(1 + at) = P_0T/273,$$
$$\text{or, } V = V_0(1 + at) = V_0T/273 = \text{pressure constant.}$$

In an open system, such as the atmosphere, where the temperature, volume, and pressure are all variables, an increase in temperature causes the air to expand, to increase in volume, to flow upward and outward, thus decreasing the weight and the consequent pressure of the vertical column affected.

Because of differences in the color of the soil, in vegetation, in shade, and in topographic relations, neighboring points are usually of different temperatures.

Pure air absorbs heat from the sun's rays but slowly. Its radiation is likewise poor. The earth's surface is heated and cooled comparatively rapidly. The lower stratum of the atmosphere is largely heated and cooled by radiation from and to the earth. Generally speaking, this stratum is cooler than the earth during the day and warmer during the night. The amount and rate of change in temperature of the lower and upper air strata are markedly different, the lower showing wide variations, while the upper and by far the greater portion of the air column is almost constant in temperature.

Computations by Gilbert[1] indicate that in the middle latitudes the average daily range of the temperature of the lower layer of the atmosphere is from 10° to 20° near the sea shore and from 20° to 35° in the interior of the continents, while that of the main body of the air is only about 4°.

A stratum of air, having become sufficiently heated at the earth's surface, streams upward in an irregular manner until the point of equilibrium is reached when it spreads out forming a layer which is warmer than the stratum either immediately above or below. Likewise in the evening when the earth's surface becomes cooler than the air, cold air flows down the hill sides and accumulates in the valleys after the manner of water in streams and lakes. So marked is this at certain seasons of the year that the difference in temperature can be quickly noticed as towards evening one descends into such an air lake.

Water Vapor.—The average amount of water vapor present at the surface of the earth is about 1.2 per cent. by volume of the total quantity of the gas, but rapidly decreases in amount with a lowering of the temperature and with increasing elevation so that it is practically absent above an altitude of 10 kilometers (32,808 feet). The pressure exerted by water vapor in the atmos-

[1] GILBERT, G. K., in the report of the U. S. Geol. Survey for 1880–1881, p. 421.

phere varies from almost nothing to more than 0.4 of an inch of mercury.

The weight of a column of air is increased by that of its contained water vapor, but it is the irregular distribution and varying amounts of the vapor which are troublesome in barometric work. These conditions may be due to inequalities in temperature, irregular distribution of bodies of water, the direction of the wind, and to other factors. However, vapor constitutes such a small percentage of the atmosphere that it usually modifies the total pressure irregularities but slightly.

Wind.—The wind tends in part to destroy but in the main to complicate pressure irregularities due to temperature and moisture, and to create others which are less subject to correction. As the strength of the wind increases, the irregularities on the earth's surface which it encounters cause greater and more complex contortions in the air, and the greater are the condensations and rarefactions of the air caused by it before and behind obstructions respectively. Similar irregularities, affecting the reading of the aneroid, exist on the windward and leeward side of the body of the observer. Gilbert states that on Mount Washington, a wind of 50 miles per hour caused the barometer to read 0.13 of an inch (equivalent to about 104 ft. in elevation) too low. Of all changes those due to the wind are the most troublesome and the most difficult to correct. They can be reduced in part by confining the work to the more favorable (less windy) times and by proper methods of observation.

Topography.—Topographic irregularities are the direct cause of many of the local variations in pressure brought about through the aid of the wind. As the lower strata of air move over the earth's surface and encounter prominences, they are retarded, diverted, and divided. These conditions result in a compression of the atmosphere before and a rarefaction behind prominences, in both compression and rarefaction through the interaction of the currents so created, and in a general complication of the existing irregularities.

Cold air descending to the earth's surface settles in topographic

depressions, causing an undue pressure at such points. Air being heated by the earth tends to form a blanket shaped by the topography, a blanket in which all barometric observations in geologic field work are taken.

Other things being equal, the error of observations tends to increase with the topographic relief and with the difference in altitude between two stations under comparison.

Recurrence of Changes in Atmospheric Pressure.—*Diurnal Changes.*—As the earth rotates upon its axis the hemispheres of day and night follow each other westward, each returning to a given point every twenty-four hours. As an area passes into night and loses the heating effect of the sun's rays, the temperature falls and the area becomes relatively cold. With the advent of morning with its sunlight the temperature rises and the area becomes relatively warm. There thus result two hemispheres which differ from each other in temperature and in the amount of the resulting evaporation. As the air is heated by the sun's rays it expands, moving upward and outward towards that hemisphere where a falling temperature is resulting in a shrinking of the air with a downward and inward flow. Owing to the rapidity of the earth's rotation as compared with its absorption of heat from the sun, the times of greatest and least temperatures of the air (least and greatest pressure respectively) are not when the sun stands in the meridian (the solar noon and midnight) and its rays are respectively the most and least intense, but a number of hours afterwards, 2 to 3 P.M. and about 4 A.M.[1]

The temperature indirectly affects the pressure by its influence over the amount and the density of the water vapor in the atmosphere. Water vapor is a true gas and is subject to the conditions described above for air, but under conditions of rapid evaporation or condensation it exerts an additional influence. As it diffuses through the air, the resistance offered by the latter may be sufficient, where the evaporation is rapid,

[1] Plympton, G. W., The aneroid barometer: its construction and use, p. 11, 1917.

to cause an accumulation of vapor in the lower stratum. The reaction due to its impeded ascent increases its elastic force and the barometer rises (pressure increases), reaching a maximum about 9 to 10 A.M.

When the temperature of the air is depressed to the dew point, moisture is deposited at such a rate that its loss cannot be at once compensated for by diffusion from the strata above and the barometer falls, reaching a minimum at about 10 P.M.

"Hence, as regards temperature, the barometer is subject to a maximum and minimum pressure each day—the maximum occurring at the period of greatest cold, and the minimum at the period of greatest heat. And as regards vapor in the atmosphere, the barometer is subject to two maxima and minima of pressure—the maxima occurring at 10 A.M., when, owing to the rapid evaporation, the accumulation of vapor near the surface is greatest, and about sunset, or just before dew begins to be deposited, when the relative amount of vapor is great; and the minima in the evening, when the deposition of dew is greatest, and before sunrise, when evaporation and the quantity of vapor in the air is least.

"Thus the maximum in the forenoon is brought about by the rapid evaporation arising from the dryness of the air and the increasing temperature. But as the vapor becomes more equally diffused, and the air more saturated, evaporation proceeds more languidly; the air becomes also more expanded by the heat, and flows away to meet the diurnal wave of cold advancing from the eastwards. Thus the pressure falls to the afternoon minimum about 4 P.M. From this time the temperature declines, the air approaches more nearly the point of saturation, and the pressure being further increased by accessions of air from the warm wave, now considerably to the westward, the evening maximum is attained. As the deposition of dew proceeds, the air becomes drier, the elastic pressure of the vapor is greatly diminished, and the pressure falls to a second minimum about 4 A. M."[1]

The amount of these variations decreases from the equator towards the poles, with the decrease in the heating power of the sun's rays. Dry climates may have no evening maximum. In

[1] PLYMPTON, G. W., The aneroid barometer: its construction and use, pp. 12–14.

such cases the minimum occurs about midnight and the only maximum about 9 A.M.

The following average daily range of pressure has been furnished by the Climatological Division of the U. S. Weather Bureau Station.

AVERAGE DAILY RANGE OF PRESSURE

Station	January	July
Galveston, Tex.	0.084 in.	0.061 in.
Dodge City, Kan	0.068 in.	0.079 in.
San Francisco, Cal.	0.064 in.	0.055 in.
Bismark, N. Dak.	0.039 in.	0.056 in.

Annual Changes.—As winter in one hemisphere is coincident with summer in the other, the condition is analogous to the change from night to day, and the air of the warmer hemisphere expands and flows towards the colder. This tends to lessen the pressure of the former and increase that of the latter.

The evaporation of water and the formation of water vapor is the greater in the warmer hemisphere, a condition which tends to depress the temperature, while on being carried into the colder hemisphere the moisture is condensed and falls as rain or snow, a condition which tends to lessen the pressure.

Thus the effects of expansion and evaporation in the warmer hemisphere are opposed to each other as are those of contraction and condensation in the colder. The result is therefore the algebraic sum of each of these two pairs of factors, and depends in the first case upon the relative changes in evaporation and temperature and in the second case upon the amount and relative changes in temperature and precipitation. The annual variation is the maximum difference between the two results. In some cases the pressure is the greater in summer and in others in winter. Annual changes are very small near the equator, 0.054 in. at Cayenne, and very large under conditions of small vapor and large temperature changes, as illustrated by a change of 0.592 in. at Irkutsk, Siberia.[1]

Irregular Changes.—Of all the changes which are detrimental to barometric work, these are the worst. They are usually

[1] PLYMPTON, G. W.: The aneroid barometer: its construction and use.

more limited in areal extent, more varied in their nature, cause more rapid and greater changes, and are so modified by stormy and windy conditions which may have originated elsewhere, and by local conditions such as topography and humidity, that but few laws concerning them have been discovered. Even these are generalities and are of no practical value in correcting irregularities.

The temperature of an area which has been subjected to intense sunshine for a number of days may become sufficiently higher than that of the surrounding region to produce a storm center. Here the heated air expands, rises, and moves outward. Cold air rushes in along the earth's surface to take its place. In this manner winds may be generated which will be felt at a distance of hundreds of miles. The wind is the great enemy of the barometer, for it so mixes and distorts existing variations as to make them no longer subject to rule.

As clouds appear to lie in a certain stratum, so is it certain that the air is stratified, composed of layers of different densities. Air which has become heated by contact with the earth does not rise by diffusing through the air above it, but breaks through at one or more points and streams upward to a point determined by its density where it again spreads out as a layer. Cold air descends in a like manner.

As the water in a stream in passing down a cataract is divided, changed in direction and speed, and here and there set into whirling motions which are carried on down the stream, so is the air affected in passing over the irregular surface of the earth. Small areas of high and low pressure are created before and behind prominences, and the existing irregularities due to stratification, moisture content, and other causes are much distorted both horizontally and vertically.

Irregularities due to stratification, moisture content, and the wind, as well as those due to diurnal changes, die out rapidly upward. Thus barometric readings in field work are taken under the worst possible conditions.

Errors due to atmospheric variations tend to increase with the

force of the wind, with the horizontal and vertical distance between two points, and with the length of time that elapses between the two readings.

Barometric Gradient.—By barometric gradient is meant the slope of the surface which unites, or is defined by, points of equal pressure. If the air was in a state of equilibrium or if the pressure varied only with elevation, such a surface would be a horizontal plane. If the changes were only periodic, such as might be due to the change from summer to winter or from day to night, such a surface would be marked by low, broad wave-like surfaces moving ever westward. But under the varying conditions described above such waves are greatly modified and their surfaces contorted. Surfaces of equal pressure as they occur one above another are no longer parallel but may have any angular relation, especially those near the earth's surface which are the more contorted.

Care and Reading of the Aneroid.—In using the aneroid, the following points should be observed.

(1) The instrument should always be carried in a case, preferably hung over the shoulder by means of a strap, and subjected to as few jars as possible. Accidents have been prevented by tying it to the case by means of a cord about a foot long which prevents it from falling to the ground should it slip from the case or from the observer's hands.

(2) It should be held in the same position for all observations, preferably with the dial horizontal.

(3) It should be gently tapped before a reading is taken. This it to make sure that the pointer has settled to the proper position but also affords an indication of the adjustment of the instrument.

(4) Some aneroids are quite sluggish in their actions. Sufficient time must be allowed for the adjustment to the change in pressure. Most aneroids adjust themselves so quickly that this precaution is needless.

(5) The pointer is commonly such a distance from the dial that parallax or a slight difference in the angle of observation

may effect the reading materially. The reading is best taken by sighting along the pointer with one eye from a point in its vertical plane or with both eyes when the precaution has been taken to eliminate parallax by turning the aneriod about its vertical axis until the line of sight is parallel to the index. If a magnifying glass is used, it must be held parallel to the dial.

(6) The distance from the aneroid in the hands of the observer to the ground is constant and need not be considered except when taking a reading on a point, the elevation of which is different from that of the point on which the observer stands.

(7) Care should be used to prevent the instrument from being unduly heated by the observer's person or the direct sun's rays. The instrument may be "compensated" for temperature but that is no reason for exposing it unnecessarily.

(8) If a temperature correction of the instrument (not necessary in this work) is to be made, the thermometer should be read first.

Tests of the Aneroid.—The method of testing and the general mechanical accuracy of the aneroid are shown by the following specifications copied from printed sheets sent out by the United States Bureau of Standards.

Method of Testing

"Before calibrating an aneroid barometer under varying pressures, the workmanship and mechanical adjustment are tested; first, by repeatedly tapping the instrument and noting the 'average deviation' of the pointer reading; second, by striking the edge of the instrument against the hand in an inclined position, first with its face to the right and then to the left, in each case reading it immediately afterward in a horizontal position and noting the difference or 'shift' of the two readings; third, by noting the 'vertical correction' or amount by which the reading of the instrument in a horizontal position exceeds the reading in a vertical position. These tests will serve to detect friction, looseness, and lack of balance, respectively.

"The aneroid barometer is then compared with a mercurial barometer diminishing the pressure at the rate of one inch of mercury in five minutes until the lowest point of the scale is reached, where it is held for five hours to determine the drift in the reading at constant pressure.

"This drift is the crucial element in determining the quality of a given aneroid barometer. It is a measure of the elastic lag in the individual instrument and the greater it is, the more noticeably will the readings depend upon the rate of change of pressure.

"The 'fast corrections' given are the corrections which are to be applied algebraically to the aneroid barometer readings in order to get the true pressures after a continuous rate of change of 1 in. of mercury in five minutes, while the 'slow corrections' given are the corrections which must be applied algebraically to readings taken after a lapse of five hours. The 'fast corrections' are determined by direct observation. The 'slow correction' at any given pressure, x inches of mercury below the initial pressure, is then assumed equal to the algebraic sum of the 'fast correction' at that point, plus x times the drift. The difference between the fast and slow corrections is a measure of the reliability of the aneroid barometer as an absolute—as distinguished from an interpolation instrument

"If in calibrating the aneroid barometer at any given speed, the corrections though large were found to vary uniformly with the pressure drop x, below the initial pressure, this would mean simply that all the scale divisions were too large or too small in the same ratio and would in no way disqualify the aneroid for use in interpolating between known altitudes or pressures. When the corrections are plotted against the pressure drop, the average deviation of the corrections from the best representative straight line may be termed the 'calibration deviation.' This is a measure of the reliability of the aneroid barometer for interpolation proper as distinguished from its use as an absolute instrument.

"The temperature coefficient of reading is the increase in the reading of the aneroid barometer at constant pressure per degree Centigrade above 20°C., the pressure corrections of the instrument having been determined at approximately this temperature. The temperature coefficient of scale value is the increase in scale value (*i.e.*, pressure change corresponding to unit change in reading) per degree C. above 20°C. For example, if it were -0.1 per cent., the aneroid would indicate a 2 per cent. smaller change at 0°C. than at $+20$°C., the true pressure change remaining the same."

Accuracy Required for Certification

"(1) In a properly adjusted aneroid barometer the average deviation by tapping should not exceed twice the 'least reading' nor in any case 0.02 in. of mercury.

"(2) (3) Neither the shift nor the vertical correction should exceed five times the 'least reading' nor in any case 0.05 in. of mercury.

"(4) The proportional drift should not exceed 1½ per cent.

"(5) The quantity expressing calibration deviation should not exceed five times the 'least reading' nor in any case 0.05 in of mercury.

"(6) The temperature coefficient of reading should not exceed 0.002 in. of mercury per degree Centigrade.

"(8) (9) The numerical value of the correction should in no case exceed 0.10 in. of mercury plus $\frac{1}{100}$ the range of the aneroid below 30 in. of mercury.

"The foregoing qualifications are by no means those of an ideal aneroid barometer and are given simply to indicate the degree of accuracy which is actually attained in commercial aneroid barometers of the first quality. No instrument will be certified whose errors greatly exceed the foregoing limits.

"In addition to these requirements, which are equally applicable to all classes of aneroid barometers, it is desirable that the instruments of each particular class should excel in those particulars which are especially important in the use to which the instrument is put."

Schedule of Fees[1]

"(*a*) Regular test, ordinary accuracy. Fee 50 cents per inch range of pressure below the 30-in. point independently of the number of instruments tested, plus $1.00 for each individual aneroid.

"(*b*) Temperature coefficient, $2.50 for one plus $1.00 for each additional aneroid submitted."

"(*c*) Short test, giving approximate correction at lowest point of scale to insure that aneroid is in good working order, but not recommended where an accuracy better than 3 per cent. of range is desired, $1.00.

"For testing of barometers to an exceptional degree of accuracy, or for calibration over an exceptional range of pressure, a further charge will be made. For testing the scales of thermometers attached to barometers the fee will be in accordance with Circulars Nos. 2 and 8, respectively.

"For educational and scientific institutions and societies a discount of 50 per cent. will be allowed on all tests under the above schedules."

[1] The testing of barometers; U. S. Bureau of Standards, Circular No. 46.

Adjustment of the Aneroid.—The adjustment of the aneroid is concerned chiefly with the tension of the spring and the position of the index. The former determines the distance over which the index shall move for a given change of pressure, and the latter its reading. Both of these are adjusted to agree with standard dials.

The tension of the spring is controlled by three adjusting screws (*D*, *D*, and *F* of Pl. III, A) but ordinarily can be readjusted by means of the screw *E*, exposed at the back of the instrument. This screw has left-hand threads so that turning it to the right increases the tension of the spring and decreases the distance moved over by the index for a given change in pressure.

The position of the index can be changed by lifting it from the pin (*L*, Pl. III, A), upon which it is mounted, and replacing it in the desired position. It can also be moved by means of the screw used for adjusting the tension of the spring, since any change in the tension changes the position of the index. Small changes can be quickly made in this manner.

A properly adjusted aneroid will almost invariably read higher in feet than bench marks referred to sea level because its scale starts about 890 ft. below this datum plane. It is not essential that the aneroid should agree exactly with the mercurial barometer and constant adjustments for small errors are to be discouraged. The method of adjusting aneroids is given here not because it is assumed that the user will adjust his own instrument, but that he may have a better understanding of its construction and limitations. As a rule all delicate instruments are best adjusted by the makers.

Use of the Aneroid.—The aneroid barometer has two uses; one as a weather indicator, and the other as a means of determining elevation. We are concerned only with the latter. The aneroid is not now so extensively used in geological work as formerly, a condition due largely to the fact that the telescopic alidade has been found to be the more practical in many cases, but there remain many conditions under which it is a valuable instrument for the determination of elevation. Inasmuch as it gets out

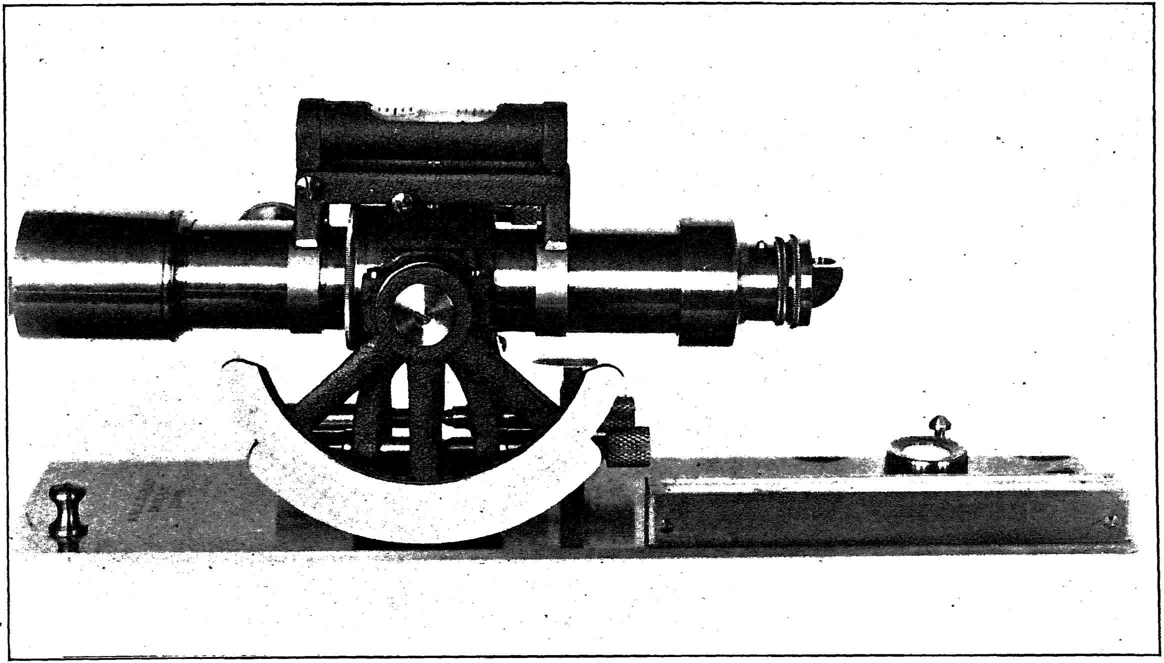
of order rather easily and its readings are subject to the irregularities of the atmospheric pressure, it can be best used only by those who understand the conditions affecting these changes. The relations of its accuracy to weather conditions and methods of use are in general but poorly understood by the users.

A good instrument will record correctly the atmospheric pressure, irregularities in its readings are due then to similar irregularities in the pressure. Weather conditions permitting, the intelligent use of the aneroid will give results sufficiently accurate for all geologic work. The chief draw-backs to its use are that the weather conditions are very often unfavorable, that a proper understanding of its limitations is not universal, that other methods of determining elevation are often more practical, and that after securing the elevations of the various points, their locations must be determined by some other means. For discussion of use of aneroid, see also pp. 101–111.

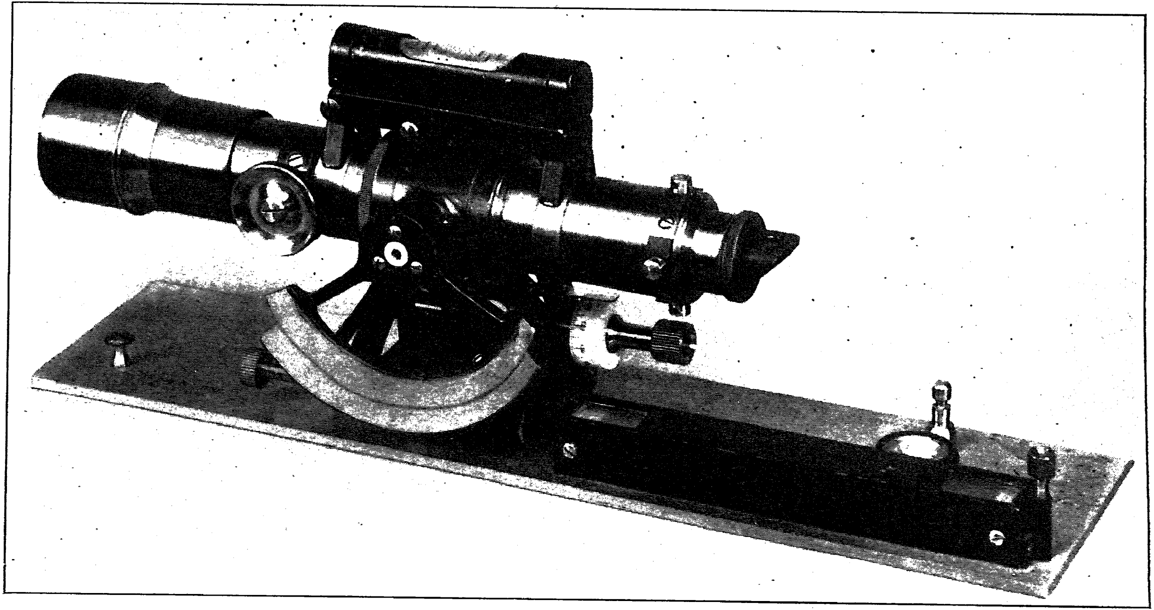
ALIDADE

An alidade has been described as a radius bearing a vernier which travels around a graduated arc or circle and which is used to measure angles. It is also applied to a straight-edge with sights such that the bearing of a point can be obtained and its direction ruled off on paper. The simplest and earliest form of the alidade is a flat straight-edge on each end of which is a raised sight. This form is still used in running traverse lines and in making topographic surveys. In such cases the distances are obtained by triangulation, by chaining, by pacing, etc., and the elevations generally by the use of an aneroid barometer and a hand level. Alidades are always constructed of non-magnetic material so that they will not deflect the compass needle.

The telescopic alidade, which is the type now most commonly employed in petroleum geology, was used by Breighton in the latter part of the 18th century. This consists of a transit telescope, with its various attachments, mounted upon a flat base or straight-edge. This change has increased the accuracy of the work and has the additional advantage of permitting rapid determination of both horizontal and vertical distances.



Gale type alidade.



Gale type alidade. (*After Young & Son.*)

Telescopic alidades vary in size, in construction, and in the number and kind of attachments. The larger and more accurate ones have a base 18 to 24 in. long and 2¾ to 3 in. wide, are mounted on a standard or pillar 3½ to 4½ in. high, and have a magnification of 16 to 32 diameters. Such instruments are more delicate, heavy, and cumbersome than are required for oil field geology, a condition which has resulted in the use of smaller instruments of the same general type and especially in the manufacture of small, compact instruments of fair illumination and magnification with or without a pillar mounting. The telescopes of such instruments have an active aperture of 11/16 to 1 1/16 in., a magnification of 13 to 18 diameters, and are mounted upon bases about 11 in. long and 2¾ in. wide. In the Gale type[1] of alidade (Pls. IV and V), the telescope is mounted directly upon the base by standards about 2 in. in height. Such an instrument is only about 3½ in. high and weighs about 4½ lb. complete in leather case with sling. It is thus easily carried about the field. Some of the small alidades have the telescope mounted upon a short pillar, as represented by the Bausch & Lomb "Frontier" model (Pl. VI).

Barrel.—The barrel of the telescope serves the double purpose of excluding objectionable light and of acting as a base to which lenses and various other attachments may be fastened.

Objective.—The objective, the lens system nearest the object, consists primarily of a double-convex lens, but in practice of a combination of two lenses one of which is double-convex and the other plano-concave. Its object is to receive and so refract the light as to form at the plane of the cross-wires a small, inverted image of the object as perfect and brilliant as is practicable.

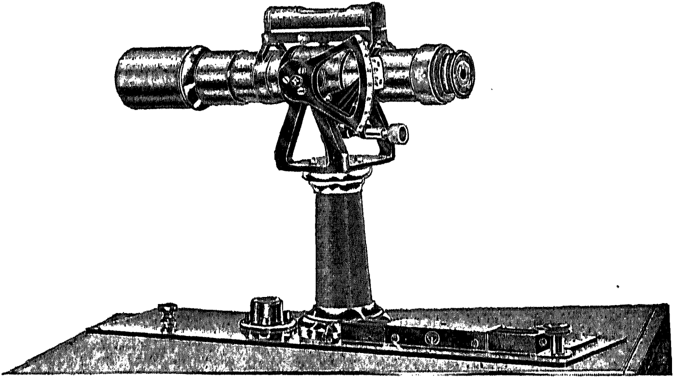
White light consists of a mixture of all colors, each of which is refracted or bent from its course differently in passing through a given substance, such as a lens. Thus the image formed by rays of each color of light will be at a different point. This is known as *chromatic aberration*. Likewise the rays of light which

[1] A small telescopic alidade planned by H. S. Gale in 1909.

pass through the edge of a spherical lens are brought together, to focus, at a point nearer the lens than are those which pass through the central portion, a condition known as *spherical aberration.* Both of these conditions are largely overcome by using lenses in pairs so related in composition and shape that one neutralizes much of the aberration caused by the other. In reality such an arrangement brings but two colors to a common focus and corrects but one zone for spherical aberration. If correction is made for the axial zone, the defect becomes rapidly more serious as either the curvature or the diameter of the active portion of the lens is increased. The shorter the telescope, the shorter the possible focal length and the greater the lens-curvature demanded; but with any given lens combination, the instrument maker has only the choice of two evils; to obtain better illumination (requiring a larger active lens aperture) at the expense of the definition, or better definition (which demands a smaller active lens aperture and less aberration) at the expense of the illumination. Both are essential and the manufacturer makes such a compromise as he thinks best for each type of instrument. The outer and more erratic rays are absorbed by black, circular diaphragms. The active aperture of the telescope is therefore the diameter of the effective portion of the objective, *i.e.*, of that portion through which light that reaches the eye has passed, and not necessarily the diameter of the objective.

The active aperture may be roughly determined by directing the telescope at the sky and moving a pointer over the surface of the objective so that it can be seen in the small illuminated circle which will be noticed at the opening of the eye end when the head is drawn back a short distance from the telescope. If the pointer is moved until it just disappears from view and the distance from it to the edge of the object-glass measured, the active aperture can be computed by subtracting twice the distance from the diameter of the objective. A hand magnifier will be of assistance in viewing the image of the objective.[1]

[1] Baker, I. O., Engineers' surveying instruments.



Bausch & Lomb Frontier type alidade.

The aperture of a telescope is of great importance since, within certain limits, it determines the amount of illumination, the degree of magnification to be used, and the resolving power.

"The *resolving power* of an objective is the measure of its ability to form separate and distinct images of two neighboring points of an object. Its value depends upon the aperture of the objective and is expressed by the angle subtended at the center of the lens by the distance separating the two closest points which it can image separately, *i.e.*, resolve. The relation connecting resolving power and aperture is $\frac{12.6}{D} = \theta$, where θ is the resolving power in seconds of arc, and D is the aperture expressed in centimeters. It applies without modification only to white points on a black background. An objective of 1 in. aperture will then resolve two points which, from the center of the objective, appear under an angle of 5 seconds.

"To make the matter more concrete, an angle of 5 seconds will include 1.53 in. at a distance of one mile. Two points separated by 1.53 in. will just be resolved by an objective of 1 in. aperture if the illumination of the object and the magnification of the telescope are sufficient. If the aperture of the objective is less than 1 in., no amount of magnification or light will suffice to dispel the appearance of the image as a single point."[1]

In other words, it is impossible to read marks of the value of tenths of a foot on a rod at a greater distance than 4128 ft. by means of an instrument which has an aperture of 1 in. or less. Naturally the above theoretical distance is not equalled in practice, the maximum figure obtained being about 3600 ft.

Eyepiece.—The eyepiece or ocular has the same defects as has the objective but not in the same degree. Its magnifying power is greater and the focal points for the various colors of light are therefore closer to the lens and closer together. However, because of its greater convexity, or magnifying power, that property of a lens which causes a flat object to appear as a convex surface and which is known as *spherical aberration* is much greater. This is likewise nearly eliminated by the use of lens combinations.

[1] Bausch & Lomb Optical Co., Metro manual, p. 78, 1915.

The eyepiece, after the manner of a microscope, is used to magnify the small inverted image formed by the objective. By focusing the eyepiece upon the cross-wires and adjusting the position of the objective until the image is brought to a focus upon this plane, the object, the cross-wires, and the stadia wires can all be seen at the same time. An inverted image is obtained by the use of a positive eyepiece and an upright one by the negative eyepiece, the chief difference being that in the latter an extra lens combination is employed to again invert the image, *i.e.*, the image is inverted a fourth time and appears right side up. The two types give what are known as *inverting* and *upright* telescopes. While it may be convenient to employ an upright instrument where it is used only occasionally, any inconvenience caused by the inverting type is soon overcome when the instrument is used often, and it is evident that some light and accuracy are lost by the use of an extra lens combination.

Magnification and Illumination.—The accuracy and rapidity of the work as well as the maximum length of sights are dependent to a large extent upon the magnification and illumination of the instrument. A fair degree of magnification is quite essential while high magnification may be detrimental in certain classes of work. Besides increasing the size, cost, and weight of an instrument, it is found that under bad weather conditions the particles of foreign material, such as dust and water, in the air may be so magnified as to interfere with the clearness of sight. Higher magnification likewise increases the apparent distortions due to heat waves and the vibrations of the cross-wires and stadia wires. Magnification is closely related to illumination and within certain limits is determined by the diameter of the objective.

The illumination varies with the intensity of the light, a condition not controlled by the instrument, and also with the active area of the objective. The distance at which a rod can be read with the same instrument varies from day to day with the intensity of the light. Readings which are difficult or impossible to get because the rod looks dark or black are due more often to

insufficient illumination than to low magnification, in fact the magnification may actually be too high to give the best illumination of the image on dark days. Not uncommonly troubles due to poor illumination are wrongly thought to be due to low magnification.

"The brightness of the image of a telescope is inversely proportional to the second power of the magnification and directly proportional to the second power of the aperture. The expression for absolute illumination of the image is, $I = A\frac{d}{m}$, where A is a constant when comparing two instruments side by side on the same object, d is the aperture of the objective, and m the magnification. A 10 per cent. increase of aperture will give over 20 per cent. increase in brightness, while 10 per cent. increase in magnification will result in about 17 per cent. loss of illumination."[1]

"If the conditions under which the engineer has to work were constant, there would be just one degree of magnification which would be the most efficient for any given instrument. In practice, however, he finds it necessary at times to take short sights and at other times long sights, now working in bright sun light and now in poor light of cloudy days or the dusk of evening.

"The ocular of a telescope will form a real image of everything in front of its anterior focal plane, including the object glass. The image of the object glass appears as a small disk of light, called the 'exit pupil,' which may be seen by placing the eye eight or ten inches back from the eyepiece. The quotient of the effective aperture of the objective divided by the diameter of the exit pupil, is the magnification of the telescope.

"The *brillance of the image* depends upon the relation between the diameter of the pupil of the eye and the diameter of the exit pupil. The image is as bright as possible when the magnification is such that the exit pupil is equal in size to the pupil of the eye. If the magnification is increased beyond this point the illumination falls off, whereas with still lower magnification there is still no gain in brilliancy since part of the light is intercepted by the iris diaphragm of the eye while, on the other hand, there is a distinct loss in resolving power.

"The aperture of the eye may vary from about 1.5 mm. in bright

[1] Bausch & Lomb Optical Co., Metro manual, p. 79, 1915.

sunlight to 6 mm. or more in the dusk. If we aim at all times to secure an image of the greatest brilliance, and still retain as much resolving power as possible, the magnification would have to be varied, then, between the limits of 17 and 4 diameters per inch of aperture. In practice we make a compromise between loss of light, due to too high power, and loss of detail, due to too low power. Longer telescopes are favored with a somewhat larger aperture and increased focal length, which makes it possible to advance the range of magnifications."[1]

Stadia Wires.—The invention of the trachymetric principle is attributed to G. Montanari who published at Cologne in 1674 a method of placing equidistant filaments of known value on a diaphragm.[2] The use of the stadia with the alidade seems to have been discovered independently by a number of observers but probably first by James Watts [3] in 1770. Professor Fontana of Florence proposed the use of spider lines in place of human hair or silk filaments in 1775, but Ramsden was doubtless the first to mount them.[4]

The determination of distance by the stadia method is based upon the relations of similar triangles. The two stadia wires are so inserted that they are on opposite sides of, parallel to, and at equal distances from, the horizontal cross-wire. The distance between these wires is usually such that as one looks through the telescope the distance between the points at which they intersect the rod (that is, the stadia intercept) is approximately equal to 1 ft. for each 100 ft. the rod is distant from the instrument.

The objective, O (Fig. 25) has two focal planes, F_1 and F, the focal length being shown as f. The two dots a and b at the diaphragm, F, represent the position of the stadia wires and c the distance from the objective, O, to the center of the telescope axis, C.

$$FO = OF' = f.$$

[1] Bausch & Lomb Optical Co.; Metro manual, p. 111.

[2] Salmoraghi, A., Geometria applicata, Milan, p. 278, 1884.

[3] Van Ornum, Prof. J. L., *Bull.* of Univ. Wis., Vol. 1, p. 354.

[4] Bausch & Lomb Optical Co.; Metro manual, p. 103, 1915.

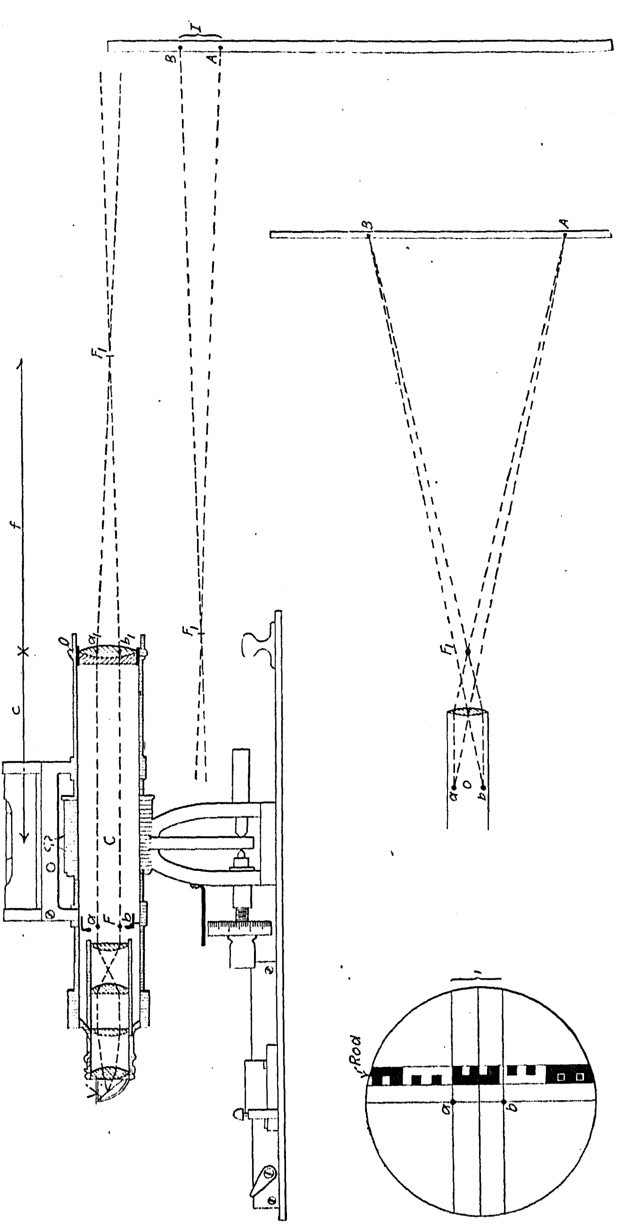


FIG. 25.—Section of alidade showing determination of distance by means of stadia wires.

A and B are the points at which the stadia wires a and b, appear to intersect the rod when viewed through the telescope.

Vision is obtained by light passing from the object to the eye. Part of the light from a point, A, on a rod at a distance, D, from the point F_1 will pass through the point F_1, on to a_1, then with refraction through the objective, O, past the upper stadia wire, a, at F, and out through the eyepiece as indicated. In the same manner light from B will pass through F_1 and b_1 and past the lower stadia wire. If the stadia wires are so placed that the distance between them is one one-hundredth of the focal length,

$$f \div 100 = ab = i,$$

then, applying the relation of similar triangles, the following formula is derived:

$$a'b' : OF' :: AB : D$$

or

$$i : f :: I : D, \text{ from which}$$
$$D = I(f/i).$$

The distance D is measured from the point F'. It varies directly with I (i and f being constants) and is equal to the constant (f/i) (usually 100 and known as K) times the stadia intercept, I. The true distance from the rod at AB to the center of the instrument, C, is

$$D + (c + f) \text{ or } KI + (c + f).$$

The value of the *constant* $(c + f)$ can be obtained by focusing the telescope on a distant object and then measuring the distance between the center of the objective and the diaphragm and adding to this the distance between the center of the objective and the center of the telescope axis. It has a value of only about 1 ft. and may ordinarily be dropped without giving an appreciable error.

Stadia markings may consist of spider web, of diamond scratches upon glass, or of platinum wire. Prominent instrument makers do not agree as to the relative value of these various

types, although the choice can often be made by considering the conditions under which the instrument is to be used. Spider web, from 0.0001 to 0.0003 in. in size, is advantageous in that it is fine, cheap, and easily applied. It is objectionable because under damp conditions it may sag and change the value of the constant K. Diamond scratches are permanent and unchanging, but it is agreed that the glass reticule which these require absorbs about 5 per cent. of the light under the best conditions, and even more if dust or moisture settles upon either side of it, since this lies in the focal plane. Platinum wires can be drawn to the desired fineness by being previously surrounded by silver, which, after the wire is drawn, is removed by acid. They are opaque and consequently easily seen, but it is claimed that they lose their elasticity and that they do not yield to shocks and jars, but break.

To verify or adjust the constant, K, or to mark a rod to be used with a given instrument, stake off a distance in even hundreds of feet approximating the length of the average sight to be taken. Place the instrument so that the center of the axis of the telescope is a distance equal to its constant $(c + f)$, behind one stake and note the points at which the stadia wires intersect the rod at the other. The space between these should be divided into as many equal divisions (usually feet) as there are hundreds of similar divisions in the distance, if K is to equal 100. Usually instruments are adjusted for a distance of about 500 ft.

The determination of distance by the stadia method is very advantageous because of the rapidity with which the work can be carried on. With care, a high degree of accuracy can be obtained, certainly sufficiently high for petroleum geology work. In general the errors of observation increase with the length of sight and are assumed to be doubled if a half-stadia interval is used and the result multiplied by two; that is, if the reading of the intercept is taken between the horizontal wire and either the upper or lower wire instead of between the upper and the lower, as is usually done. The maximum distance that can be determined directly by simple stadia wires and cross-wires without

the use of other attachments is 200 times the length of the visible portion of the stadia rod. In some instruments a third stadia wire is inserted midway between one stadia wire and the horizontal cross-wire. In such cases the maximum length of sight directly determinable would be 400 times the visible length of the rod, using one-fourth stadia intercept and multiplying the result by four.

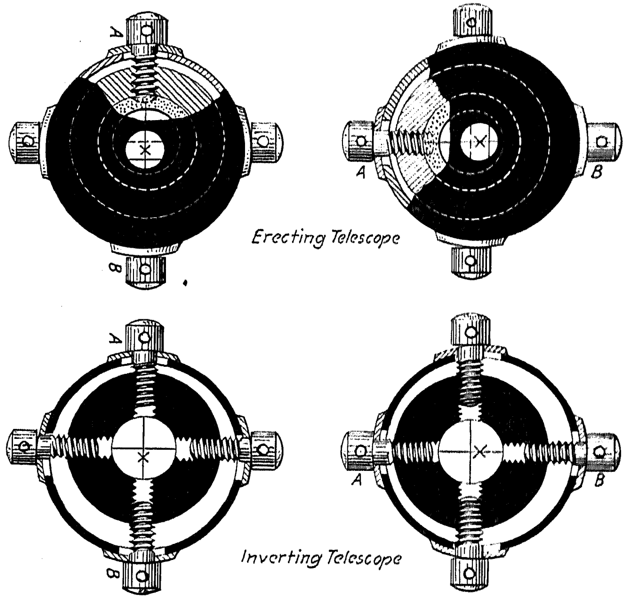


FIG. 26.—Reticule showing method of adjusting cross-wires. (*After Berger.*)

To Replace Stadia Wires.—It sometimes becomes necessary to replace stadia and cross-wires. If these are constructed of spider web, no great difficulty is usually experienced in replacing them in a satisfactory manner.

The wires are mounted upon a ring known as the reticule. To take this from the telescope, remove the two horizontal screws (Fig. 26), rotate the reticule 90° with the vertical screws as an axis, insert a pencil or sharpened stick into the horizontal

screw hole now exposed, remove the two vertical screws, and withdraw the reticule by means of the pencil or stick which should now be supporting it.

Old web may be used, but it is usually best to catch a spider, preferably one of the small black kind, and cause it to spin some fresh, clean web. If the spider is shaken off the end of one prong of a small forked stick, and the resulting web caught across the other prong, it is then in an ideal position for mounting.

In most cases the relative position of the wires cannot be changed, their proper position being indicated by scratches on the reticule. These lines having been determined and the reticule mounted in a horizontal position, the web across the fork of the stick is carefully lowered into position, accuracy being obtained by the use of a magnifying glass. By mounting the reticule above the general surface, the lowering of the forked stick to that surface may produce a proper, constant tension in the web, which is then fastened in position by placing a small drop of thick shellac at each side of the reticule at the point the web crosses it. After being allowed to stand a few minutes, the excess web can be safely broken off. The desired number of wires may be secured by simply repeating the operation. Some prefer to secure the proper tension of the web by attaching a small piece of paper as a weight to each end. The reticule is finally replaced in position, and the vertical and horizontal screws inserted.

Adjustment of the Line of Collimation.—The line of collimation is the line of sight as defined by the cross-wires and the optical axis of the objective when the two are in perfect adjustment with respect to each other. To test, sight upon some object and note carefully the position of the intersection of the cross-wires as referred to the field of view. Rotate the telescope slowly on its longitudinal axis and note whether or not the point of intersection of the cross-wires appears to move. Rotate 180° and adjust for one-half the apparent error. Repeat until correct.

The adjustment consists of moving the reticule to which

the cross-wires and stadia wires are attached, to such a p tion that the point of intersection of the cross-wires coinc with the optical axis of the objective. The reticule is hel place by four screws (Fig. 26) by means of which it can be mo in any direction normal to the longitudinal axis of the telesc and at the same time, be held firmly in position by means of compression between opposing screws.

Because the image of the reticule is inverted one or m times before it reaches the eye, in adjusting the wires of inverting telescope they should be moved in the direction wl will apparently lessen the error, while with an erecting t scope, they should be moved so as to apparently increase Most, if not all, telescopic alidades are of the inverting type, those with a prismatic eyepiece appear to be only semi-inv ing as the image is right side up although the right and sides are exchanged. In this case the movements of the vert screws are governed by the laws of the erecting telescope the horizontal ones by those of the inverting type.

Vertical Arc or Circle.—The vertical arc by means of wl the inclination of the telescope is determined in degrees minutes may be graduated in various ways. In small alida such as the Gale type, only angles which are less than ab 28° can be read directly because at this point the end of telescope strikes the base. The arc used has, then, an ang value of about twice this angle, a comparatively large rad and rather large, legible divisions. Commonly it is laid in degree and half degree divisions and supplemented either a single or a double, direct-reading vernier (Pl. IV Fig. 27).

The vernier is made by laying off on one or both sides of a z mark 30 equal divisions, such that their sum is equal to 29 of half-degree divisions of the arc, that is, each of these divisi is one minute smaller than the half-degree divisions, or is o 29 minutes. This being the case, each successive line on t side of the zero towards which the degree reading is being ta is one minute closer to the last line it passed on the arc tha

the preceding one; and consequently the number of minutes to be added to the arc reading is determined by noting the number of divisions that occur before a mark on the vernier coincides with one on the arc.

The numbering of the divisions of the arc may be arranged as desired. In many cases the no-angle point (horizontal posi-

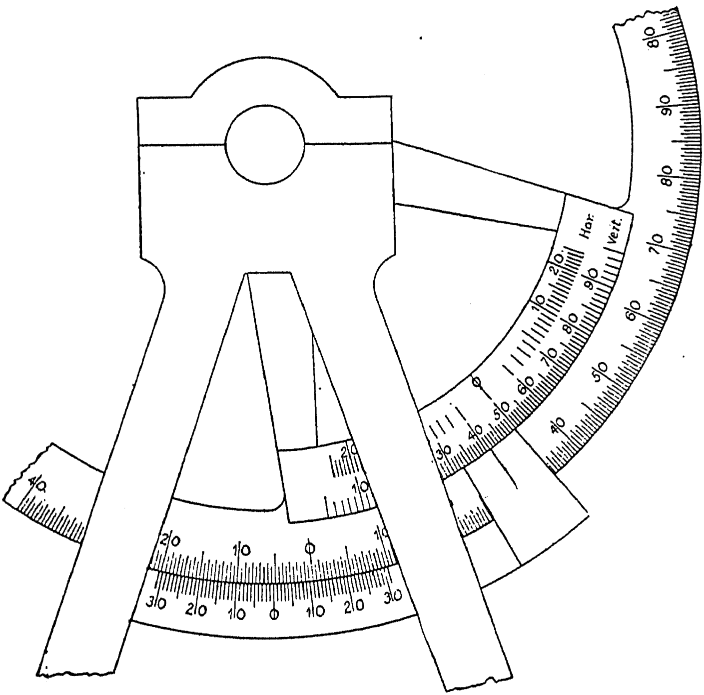


FIG. 27.—The vertical and Beaman stadia arcs. (*After Gurley.*)

tion of the telescope) is marked zero and the degrees numbered in groups of ten in each direction therefrom (Fig. 27). The angles of sights on points higher than the instrument will then be read on one side of this zero mark and of those lower than the instrument on the other, making it necessary to use two verniers

and to prefix some sign, such as + or −, to each reading in order to distinguish one from the other. These very fruitful sources of error can be largely eliminated by indicating the no-angle position on the arc by some number, such as 30, larger than any inclination at which the telescope can be read (Pl. IV). In marking the arcs so that the numbers range downward on one side of the no-angle position and upward on the other, some instrument makers indicate sights of elevation by numbers larger than that of the no-angle point while others show sights of depression by such readings. The former is to be preferred.

Beaman Stadia Arc.—The determination of elevation by means of the vertical arc is made by multiplying the stadia intercept by a function ($1/2 \sin 2v$) of the angular elevation of the point. It is evident that in place of graduating an arc in degrees it can be laid off in terms of the desired function and that the computations can be further simplified by marking only those angles the values of the desired function of which are simple whole numbers. Thus if the angular elevation of a point is two of these divisions, its elevation above the instrument can be quickly determined by multiplying the stadia intercept by two.

Except in horizontal sights, the stadia constant (usually 100) times the stadia intercept on the rod gives only the approximate inclined distance, the horizontal distance being obtained by multiplying this by another function ($\cos^2 v$) of the vertical angle. An arc can likewise be laid off in simple whole numbers of this function, or in per cent. so as to show how much the approximate inclined distance must be diminished to obtain the true horizontal distance.

The Beaman stadia arc (Fig. 27) has such graduations. It was devised by W. M. Beaman, a topographer of the United States Geological Survey, and patented in 1906. It consists of two scales on an arc, or circle, attached to the vertical limb of the telescope after the manner of the ordinary vertical arc, the three usually being inscribed on the same arc or circle. One method of attaching the Beaman stadia arc is shown on Plate

IV and in Fig. 27, and another in Fig. 28. The scale marked "Vert.", which reads 41 in Fig. 27 is for determining elevation. The upper scale, marked "Hor.", which reads a little less than 1 (per cent.) in Fig. 27 is for correcting the distance as determined by stadia reading.

The V-graduations represent those angles, through which the telescope can be rotated, the values of the function 1/2 sin $2v$ of which are simple whole numbers. The spacing is therefore

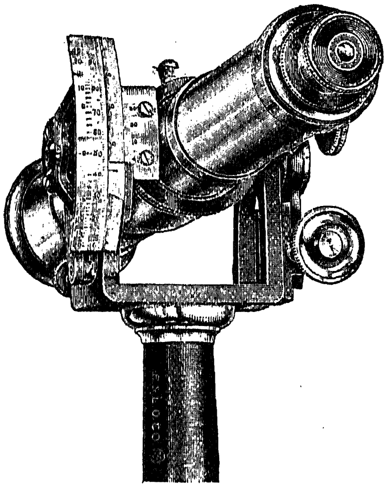


FIG. 28.—The Beaman stadia arc. (*After Bausch & Lomb.*)

not uniform, as shown by the accompanying table of Beaman stadia arc divisions. (See p. 60.)

In order to avoid trouble and possible error in noting and recording that the point on the rod is higher or lower, as the case may be, than the instrument, the divisions of the V-scale are so numbered that the zero point is indicated by 50. All readings less than 50 are for points lower than the instrument and vice versa. The value of the angle is the difference between the reading of the arc and 50. The H-scale reads in per cent. and, since the horizontal distance is always shorter than the inclined,

the latter is diminished by this per cent. of itself to obtain th former.

VALUES OF BEAMAN STADIA ARC DIVISIONS[1]

No. of interval	Angle ($\frac{1}{2}$ sin 2v) °	′	Difference in minutes	No. of interval	Angle ($\frac{1}{2}$ sin 2v) °	′	Difference in minutes	No. of interval	Angle ($\frac{1}{2}$ sin 2v) °	′	Difference in minutes
0		00.00									
			34.38				36.16				43.3
1	0	34.38		16	9	19.89		31	19	09.48	
			34.39				36.42				44.2
2	1	08.77		17	9	56.31		32	19	53.75	
			34.42				36.70				45.2
3	1	43.19		18	10	33.01		33	20	39.00	
			34.47				37.00				46.
4	2	17.66		19	11	10.01		34	21	25.31	
			34.52				37.32				47.
5	2	52.18		20	11	47.33		35	22	12.81	
			34.59				37.71				48.
6	3	26.76		21	12	25.04		36	23	01.63	
			34.68				38.08				50.
7	4	01.44		22	13	03.12		37	23	51.94	
			34.77				38.49				51.
8	4	36.21		23	13	41.61		38	24	43.93	
			34.88				38.95				53.
9	5	11.09		24	14	20.56		39	25	37.82	
			35.02				39.44				56.
10	5	46.11		25	15	00.00		40	26	33.90	
			35.16				39.97				58.
11	6	21.27		26	15	39.97		41	27	32.54	
			35.33				40.54				61.
12	6	56.60		27	16	20.51		42	28	34.20	
			35.50				41.16				65.
13	7	32.10		28	17	01.67		43	29	39.50	
			35.71				41.85				69.
14	8	07.81		29	17	43.52		44	30	49.27	
			35.92				42.58				75.
15	8	43.73		30	18	26.10		45	32	04.74	

[1]. Bausch & Lomb Optical Co.

Gradienter Screw.—The gradienter screw is a modification of the vertical arc tangent screw and is so constructed as to furnish a very convenient means of determining vertical and horizontal distances. Its first use for this purpose is credited to Professor Stampher of Vienna in 1873 and the graduated drum attachment to Stebbinger. It consists of a carefully threaded screw which passes through a nut (Fig. 29) fastened to one of the standards, and bears against the clamp arm, the system being firmly held together by means of a spring. In some cases the screw is attached to the clamp arm and bears against a lug fastened to the standards or base, but the result is the same.

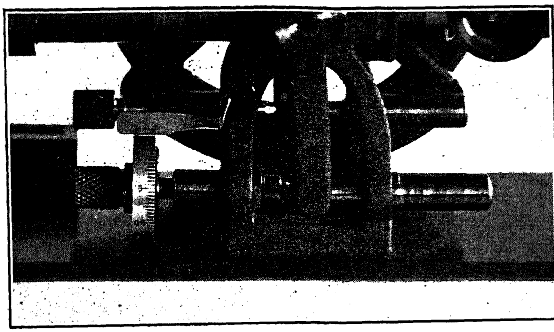


FIG. 29.—The gradienter screw.

As the name implies, the gradienter screw was originally intended for measuring in per cent. the inclination of the line of sight, but inasmuch as this is a quick and simple method of expressing the relation of horizontal and vertical distances, it is commonly used for such determinations. Since this relation of an angle is expressed by the value of its tangent (tan V = perpendicular/base = inclination of hypotenuse in per cent.), it is desirable that it be read directly as such. Because only angles the tangents of which may be expressed in simple numbers, such as 0.01, 0.02, etc., are commonly taken, the computations are much simplified.

The desired value of rotation is obtained by giving the pitch

of the screw and the length of the clamp arm such a relation that one complete revolution of the screw will move the telescope through an angle of 34′ 23″, the tangent of which is 0.01. Thus the length of the rod passed over by the horizontal wire during one rotation of the screw is 1 ft. for each 100 ft. the rod is distant from the center of the instrument, and the grade of the line of sight is 1 per cent. for each rotation from the horizontal. To aid in accurate determinations, a milled head or drum divided into 100 parts is attached to the screw and a graduated horizontal bar so placed as to indicate the number of complete revolutions.

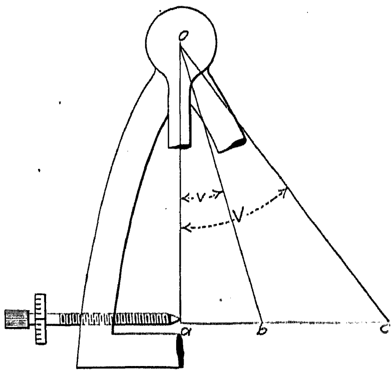


FIG. 30.—Theory of gradienter screw construction.

Some instrument makers have used a screw and arm so related that two revolutions are required to turn the telescope through the above angle. In such cases the drum is divided into fiftieths and one division still corresponds to a grade of 0.01 per cent.

Gradienter screws are constructed according to two principles; the one in which the axis of the screw is always tangent to the same vertical circle and the other in which it is not. The first is theoretically correct in that it turns the line of sight through angles the tangents of which are proportional to the number of revolutions of the screw, the second is approximately so for small angles.

In Fig. 30, let O represent the horizontal axis of the telescope,

the line aO the initial position of the clamp arm upon which the gradienter bears, bO the position of the arm for n rotations of the gradienter screw giving the angle v, and cO a third position of the arm for m rotations of the gradienter screw giving an angle V. If the pitch of the thread be designated by z, then, assuming, that the screw acts in the direction ac, and that the angle caO is $90°$,

$$\begin{aligned} nz &= ab, \\ mz &= ac, \\ \tan\ v &= ab/aO, \\ \tan V &= ac/aO, \\ \therefore \tan v : \tan V &= ab/aO : ac/aO = ab : ac, \\ &= nz : mz = n : m, \end{aligned}$$

indicating that in this case the tangent of the angle varies proportionally to the number of rotations of the gradienter screw.

Base and Straight-edge.—The straight or "fiducial" edge is the right hand edge of the base which is beveled and graduated. These graduations should be in the decimal scale to facilitate the plotting of decimal rod readings and, unless otherwise ordered, usually consist of inches subdivided into tenths and fiftieths. The front and back edges of the base should be straight and parallel for it is sometimes convenient to use the left hand or back edge, thus permitting the instrument to remain on and more near the center of the table, when taking sights from stations near the left side of the table top. The base is usually of brass which tarnishes readily and, if in contact with the paper, tends to soil its surface. In some cases this has been avoided by mounting the base upon brown paper, but is now successfully overcome by painting the bottom of the base with a white enamel which does not tarnish, slips readily over the paper, and can be easily cleaned.

Spirit Levels.—Alidades are equipped with leveling devices for both the base and the telescope. Bubble-tubes may be used in either case, but commonly a bull's-eye level is used for the base. If a bubble-tube is carefully leveled and then its ends reversed, the difference in the two positions of the bubble

will be twice the error in adjustment. The striding level must be tested in place on the telescope; it is leveled by means of the tangent screw, removed, and replaced in a reversed position. A base level is leveled by means of the support upon which the base rests and is reversed by reversing the alidade.

Most level carriages are intended to be adjusted at one end only, this end being held in position between two nuts or by means of a screw and a spring. The bubble-tube is adjusted by raising or lowering, as may be necessary, one end of its carriage by means of a vertical screw shown on the bottom of the carriage, or by opposing capstan nuts at the end. An inspection of the bubble will show whether this end is to be raised or lowered and usually will indicate which way the screw should be turned. Rule-of-thumb methods as to the direction in which the screw is to be turned are not practical, so that if it cannot be readily seen by inspection, a trial turn will quickly show which is the right direction. At the first attempt it is best to adjust only for approximately one-half the difference in position shown by the reversed bubble, the final adjustment being obtained by a number of trials.

The bull's-eye level is of low sensitiveness so that slight variations are neither readily noticed nor of particular importance. It may be tested by placing the alidade upon a surface that is known to be level. If the bubble does not assume a central position with respect to the circular graduations, it should be made to do so by adjusting the three small screws shown in Fig. 20.

Care of Alidade.—The alidade should be carefully guarded against shocks which will change the adjustment of its parts, and must be kept free from dust and moisture which may interfere with the clearness of vision and the working of the parts. It should be kept in its case when not in use and when carried in a vehicle should be given a place where it will receive the least shaking. Not uncommonly it is carried on the cushion in the seat.

When handled it should be supported by the base. Clamps should be tightened no more than necessary and tangent screws should work freely and never be forced. Parts should be cleaned before being oiled, and, if covered with oil and dirt, should be thoroughly scrubbed with soap and water. This is particularly applicable to tangent screws, which are liable to stick in cold weather. In general, parts exposed to the dust are not to be oiled, as oil catches dust which binds and cuts the bearings. It is recommended that only a good grade of watch-oil be used, but when this is not available, one may substitute plumbago, rendered marrow, or, if necessary, pure vaseline, although the latter is likely to have some chemical action on brass. Rendered marrow and vaseline, especially the former, may be too thick for winter work. All excess oil should be carefully removed.

The lenses must be clean. It is better to prevent them from getting dirty by the means regularly provided, than it is to clean them often, as the latter tends to destroy the polish of the surface and the sharpness and brilliance of the image. Dust may be removed with a fine, clean brush (preferably of camels' hair). If a brush is not available or sufficient, a piece of chamois skin, a clean, soft piece of linen or silk or, if necessary, a clean pocket handkerchief lightly applied may be used. In no case use the fingers because a thin film of grease is worse than dust. If a liquid is needed, use alcohol, but do not permit it to touch the lacquer on other parts of the instrument, or to come into contact with any Canada balsam cement which may be present. It is seldom necessary to clean lens surfaces other than the outside of the objective and eyepiece. In no case should a lens system be taken apart because a slight relative shifting of its parts might greatly injure the optical properties of the telescope. No amount of adjusting would correct for such an error. It is even possible that in screwing an objective mounting into place a difference of a fraction of a turn may be sufficient to destroy the adjustment of the line of sight but this can be corrected.

Moisture should be kept out of the telescope. If water gets

into it, remove the eyepiece and dry the parts. If water collects on the objective, remove it, dry it carefully, and fill the barrel with dry air. Use care not to batter the slots in screw heads and never take things apart unnecessarily.

Adjustments of the Alidade.—The uses to which the alidade is put are based upon the assumption that the following relations exist between its parts. (1) The horizontal axis of the telescope is (*a*) parallel to the base and (*b*) normal to the "fiducial" edge; (2) the longitudinal axis of revolution of the telescope is normal to the horizontal axis; (3) the longitudinal axis of revolution coincides with the line of collimation; (4) the line of sight as determined by the intersection of the cross-wires coincides with the optical axis of the objective; (5) the axis of the collars upon which the striding level rests coincides with the longitudinal axis of the telescope; and (6) the base and striding levels are in proper adjustment.

Numbers 1, 2, 3, and 5, are carefully adjusted at the factory and no means is provided for their correction. Number 4 concerns the adjustment of the line of collimation and is described under stadia wires. Number 6 is described under spirit levels.

LEVELING AND STADIA RODS

The rod is used in determinations of distance and of elevation. In the United States, distance and elevation are measured in feet so that it follows that the rod should be graduated into foot divisions. For simplicity in computations the feet are further divided decimally, usually into tenths, because in petroleum field work, readings and computations are only carried out to the nearest tenth of a foot. The present tendency in instrument work is to use fewer but better chosen stations, fewer set-ups, and longer sights. These in turn necessitate that the rod be long and of high visibility, that it be sufficiently strong to stand the wear and tear, and yet that it be light enough to be carried with no great discomfort. Inasmuch as these requirements are opposed to each other, a "happy medium" must be found which best fills the particular need.

Description of the Rod.—Commonly rods are made of clear, straight grained, well-seasoned white pine (sometimes specified as "rafted" pine), but yellow poplar and cyprus are also used. White pine is readily obtained, is of uniform grain, and is easily worked. It is lighter and less inclined to warp than either yellow poplar or cyprus but is softer and less strong. Yellow poplar is heavier and harder than cyprus but is inclined to warp, while cyprus is inclined to splinter.

Such rods may consist of one, two, or three sections, the sectional types folding or sliding together so as to be of a convenient length for carrying and for transportation. One-section rods are inconvenient and seldom used. Two-section rods can be folded to a little more than half their length, are fairly strong and convenient, and are in general use. Three-section rods are used to some extent, largely because of their convenient length when folded. Naturally they tend to be less strong and steady and of greater weight than those which consist of one or two pieces only.

The visibility requirements necessitate that the rod be not less than 3½ or 4 in. wide, the determination of distances demands that it be 14 or 15 ft. long, and convenience in carrying requires that it be as light as is consistent with the above requirements, and still be sufficiently strong. Two of the dimensions having been fixed, the weight is kept fairly low by making rods of minimum thickness. This is about ⅞ or ¾ in. at the center, the sections tapering to ½ in. at the end. To reduce the weight still further, the face may be rabbited to the extent of ⅛ of an in., or the back may be kerfed with a saw or dado.

For fastening the sections together a pair of 1½ by 6 in. strap hinges are desirable, although for very light rods the hinges can be smaller. It is best that there be two hinges, the outer end of the joint of each being brought flush with the outer edge of the rod in order to give a maximum resistance to side strains.

To hold the rod in position when open, one of several devices may be used. A short piece of the same material as the rod may be screwed to the back of the upper section so as to overlap

the joint about 4 in. The rod can then be locked open by means of a small door bolt or a hook. This is probably the most satisfactory method. Another way is to use a wooden slide about 14 in. long, 1½ in. wide, and ¾ of an inch thick so arranged as to slip through two loops on the lower section and into a loop

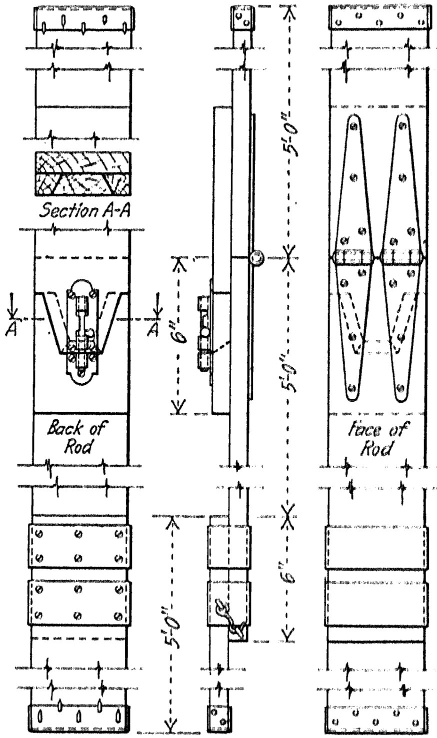


Fig. 31.—Details of stadia rod construction.

on the upper section. The chief objection to this construction is that the loops often get bent. If the lap joint is used the piece should be cut as shown in Figs. 31 and 32, as this not only braces it against side strains but forces it into the proper position for locking. If a hook is used the lap can be a straight piece with a slot near one end to receive the screw eye.

A 15-ft. three-section rod can be folded up to measure 5 or $5\frac{1}{2}$ ft. over all, depending upon the type of fastening used. If both joints are of the hinged type, three pieces each 5 ft. long will be necessary. If constructed with slide joints the pieces must be enough longer to make up for the lap when the rod is open. More often the upper joint is hinged and the lower arranged to slide. In this case the middle section should be 6 in. longer than the others. A sleeve of galvanized iron is made to accommodate this section and fastened to the upper

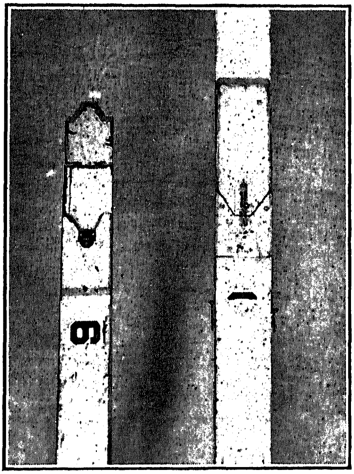


FIG. 32.—Lap-joint construction of stadia rod.

end of the lower section so that the middle section is free to work up and down in it. When extended it is held in place by a small hook.

The ends of the rod should be protected by being bound with galvanized sheet iron, and the face of the rod prevented from rubbing when the rod is closed by the use of rubber bumpers.

Following are specifications of rods constructed in accordance with the descriptions here given. These rods have proved very satisfactory in practice.

In the experiments with rods carried on by the authors, the first 15 constructed weighed 12 lb. each. Rod No. 6 (table of rod specifications) shows a reduction in weight of 2.25 lb. due to making the rod thinner. Rod No. 3 shows the latest design in which the weight has been reduced to nearly half of that of the first rods.

Table of Rod Specifications

Rod No. 6

Material	white pine
Length	15 ft.
Sections	2
Width	3.9 in.
Thickness	0.8 in. at center 0.5 in. at ends
Hinges	6 × 1½ in., strap
Joint	lap and bolt
Ends bound with sheet iron.	
Weight	9.75 lb.

Rod No. 3

Material	white pine
Length	15 ft.
Sections	2
Width	4 in.
Thickness	½ in. tapered and rabbited.
Hinges	1½ × 5 in., strap.
Joint	lap and bolt.
Ends bound with sheet iron.	
Weight	7 lb.

Rod No. 4

Material	poplar
Length	15 ft.
Sections	3
Folded length	5.5 ft.
Thickness	¾ in.
Tapered to	½ in.
Hinges	1½ × 6 in.
Upper joint	lap type
Lower joint	sliding
Ends bound with sheet iron.	
Weight	10 lb

Visibility of Rods.—The visibility of a rod, or the ease with which its divisions can be recognized at a distance, varies with its width, with the colors used, and with the design painted upon its face.

In general all good designs can be arranged so that their visibility will be about equally increased by widening the rod, or by extending the design over its edges.

Rod designs should be painted in two colors which contrast strongly with each other and with the average background, and one of which reflects a maximum amount of light to the eye of the observer. Any two complementary colors, such as blue and yellow, would fulfill the first requirement but not the second. All such objects are seen by reflected light and the more light they reflect the more readily are they seen, except when seen in contrast with some other color. All fundamental colors, such as blue and yellow, absorb much of the incident light and reflect that of their own color only.

White and black differ much from the average background, are directly opposed to each other, and reflect more and less light respectively than any other colors.

From the above it follows that, other things being equal, the best results are obtained by painting designs in black upon a white background and that the "markers" (known points of exceptional visibility) should be essentially black. Other colors are often used to number the foot-marks, but they are commonly read at short distances only.

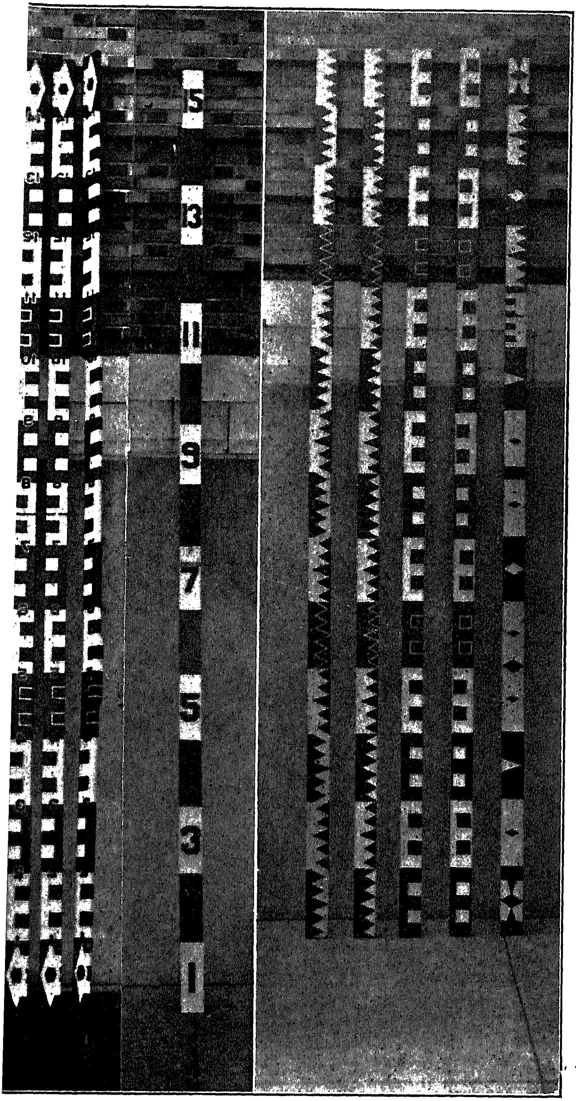
In painting a rod, good results can be obtained by using a good grade of white lead for all but the last coat which may consist of a white enamel, the pigment of which is 100 per cent. zinc oxide. Enamel will not adhere well when painted directly on the wood but gives a more permanent white color than a paint or other enamel which contains lead. Objectionable reflections may be destroyed by rubbing the face of the rod with fine pumice stone or rotten stone and oil. However, reflections from the rod are not undesirable as they are of more value in locating the rodman than they are injurious in reading the rod.

The discussion of the visibility of different rod designs is best limited to their appearance at fairly long distances, 2500 ft. or more, because there is less need of careful choice of designs for short sights, almost all patterns being read quite easily.

Other things being equal, the reading of rods at distances depends upon the visibility of the designs painted upon them, in the study of which three points are to be considered: first, the ease with which the decimal or fractional divisions of each foot can be separated from each other; second, the readiness with which the foot-divisions can be separated from each other; and third, the ease with which the number of any foot can be determined. A rod may excel in one of these and be poor in the other two.

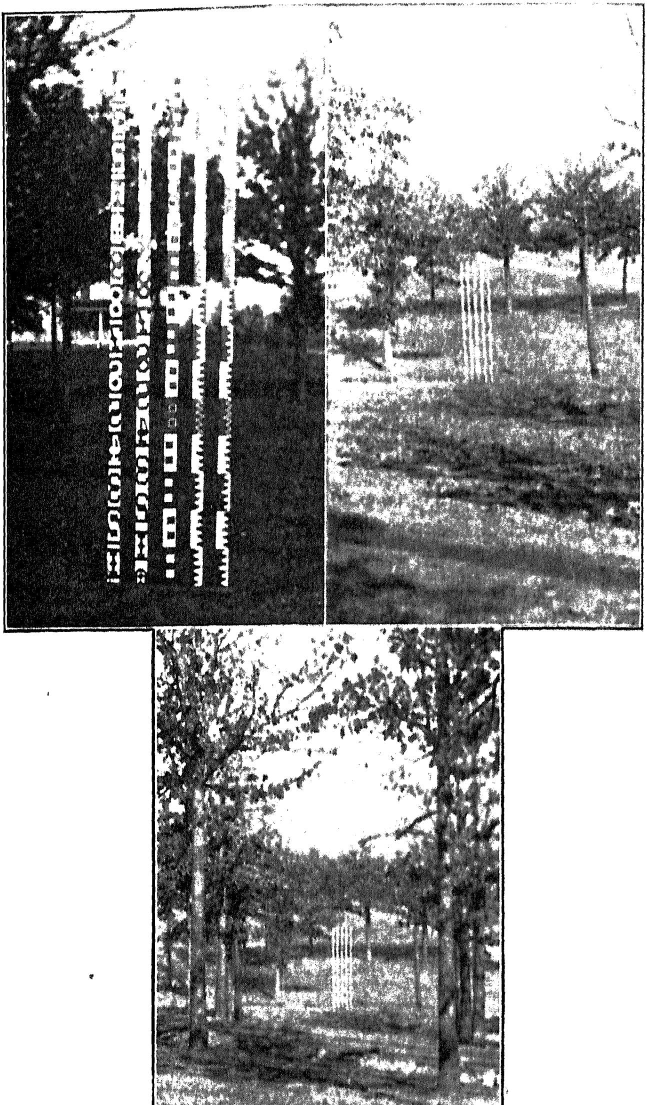
For every distance from the telescope there is a distance by which two points must be separated in order that they may be seen as such (See p. 47). Thus an alidade with an active aperture of 1 in. which is about the average size, cannot, even under the best possible conditions, resolve as two points, two objects separated by one-tenth of a foot at a greater distance than about 4100 ft. It is to be expected that under the usual working conditions the reading of tenths of a foot will be impossible at distances greater than about 3000 ft. In such cases the visibility of two points is determined by the distance between them rather than by their size.

General engineering stadia rods have about the same proportion of black and white in adjacent foot-divisions. At distances such that the decimal divisions blurr and the colors blend together, the color of each foot-division tends to become that of its average color and can therefore be seen but little if any farther than the decimal divisions. Greater foot-visibility can be obtained only by an "unbalanced" design, that is, by one in which the ratio of black to white is not the same in adjacent foot-lengths. Our experiments have shown that beyond this point the foot-visibility varies directly with the difference in this color ratio. Under these conditions the rod appears to consist of alternate



Stadia rod designs.

PLATE VIII



Relative visibility of rod designs.

black and white foot-divisions and has what we have termed "blended" visibility, *i.e.*, the foot-divisions are separately visible after the decimal divisions are no longer so. The ratio of black to white may be affected by the choice of the design, by the manner in which it is placed on the rod, by the use of positive and negative feet (using the same design but the opposite colors), and by extending the painting of the design over the edges of the rod.

Divisions on the rod corresponding to tenths of a foot are desirable but can be estimated with a fair degree of accuracy if the foot-marks are visible. Foot-marks on the rod are essential but even they may be estimated in some side-sights. It not uncommonly happens that the foot-marks can be seen but momentarily so that the number of a mark cannot be determined by counting from the end of the rod. This often tests the ingenuity of the instrument man who soon learns the height of the top of the rodman's head, of his shoulders, of his waist line, and of his leggings, so that with one statia wire on the top of the rod he is able to determine or estimate the reading of the other. This method is not entirely satisfactory and the use of "markers," points on the rod which can be seen at any working distance, is now quite general. These may consist of special designs or of heavy black bands from two-tenths of a foot to a foot wide across the rod at intervals of about 5 ft. By means of these, and by utilizing the top and bottom of the rod, the number of foot-marks that must be counted or estimated is never more than five and is usually three or less, a number which can be quickly grasped by the eye or easily estimated; and the instrument man can more often tell with what foot-mark on the rod he is dealing. The white diamond shown on several rods on Plate VII is used to better distinguish the top foot of the rod when it is partially obscured by brush.

It is desirable if possible to use a design which has "markers" which is reversible (*i.e.*, has like characters present at equal distances from each end), which has sufficiently high foot-visibility for long sights, and which also has, if possible, decimal divi-

sions to be used for short and more accurate readings. All sorts of rod designs are used in the oil fields and some geologists have gone so far as to use simply alternate plain black and white foot-divisions (Pl. VII).

The use of special designs for each foot (Pl. VII) is not uncommon but they cannot be readily recognized at a distance. Many rods have the feet designated by small red numbers which can be read only at distances of a few hundred feet. Such numbers are convenient in close sights in which the relation of the foot-division to a "marker" cannot be seen because of an obstructed view.

After testing all the designs which have been brought to their attention, the authors have adopted the unbalanced saw-tooth and square designs shown in Plate VII, as being the most satisfactory.

Percentage of Black in Alternate Foot Divisions of Rods in Plate VII

	Odd feet	Even feet	Difference
Positive saw-tooth design	51.5	28.5	23.0
Combined negative and positive saw-tooth design	71.5	28.5	43.0
Square design	76.0	24.0	52.0

The distance at which any rod design can be read varies with the atmospheric conditions and with the telescopes used. These rods were collectively viewed through a Young & Son's alidade (18 diameter magnification and 1$\frac{1}{16}$-inch aperture), and through a Bausch & Lomb alidade (16 diameter magnification and 1-inch aperture) upon a day of only fair visibility, the heat waves being quite pronounced. At a distance of 3600 ft. the foot-divisions of all, and the two-tenths divisions of the square design were clearly visible, while the tenths divisions of the saw-tooth designs could be seen but not counted. At 4200 ft. the same condition was true except that the saw-tooth divisions could not be separately distinguished. At 5280 ft. the two-tenths divisions could still be read but had reached the limit of their visibility. The foot-divisions of all were still distinct. At 7700 ft., the foot-divisions

of all could be seen and counted by reference to the markers, but had reached the limit of their visibility. Plate VIII illustrates the relative visibility of rods.

Summary.—(*a*) Alternate foot-divisions of a stadia rod should differ as much in their relative amounts of black and white as is consistent with the design.

(*b*) Foot-markings should be extended over the edges of the rod.

(*c*) Squares are thought to have better visibility than triangles.[1]

(*d*) "Markers" are desirable and should not be more than 5 ft. apart.

(*e*) There should be some method of recognizing the individual feet other than by reference to "markers." This can be done by numbering the feet or by using a different design for each foot-division.

(*f*) Other things being equal, the simpler the design the better.

(*g*) A rod of low foot-visibility can be quickly improved by painting on its back one of alternate white and black feet and using this side for long sights (and *vice versa*).

(*h*) A rod of low foot or decimal visibility can be improved by painting a design of good decimal visibility on one-half and one of good foot-visibility on the other. However, this decreases the value of the rod for leveling purposes.

PLANE TABLE

The plane table is one of the oldest surveying instruments now in use, having been known and used in Europe more than three centuries ago. Its invention is attributed to Johann Praetorius in 1590.[2] For many years it has been used in government work in Germany, Austria, Italy, India, and by the United

[1] This was suggested by LESTER JONES, Superintendent, U. S. Coast and Geodetic Survey, who states: "Our experience has led to the conclusion that squares are preferable to triangles, especially for long distances." Personal communication.

[2] VAN ORNUM, J. L., Topographical surveys, their methods and value, *Bull.* Univ. of Wis., Vol. 1, No. 10, 1896.

States Coast and Geodetic Survey, but it is only within the last few years that its value in commercial engineering work has been appreciated.

The plane table consists essentially of a drawing board mounted upon a firm tripod in such a manner that it can be rotated in azimuth (Fig. 33). Leveling screws, extension legs, etc., may or may not be desirable.

The top is of firm soft wood, usually well-seasoned white pine, and so constructed as to be strong and resistant to warping, the last two features being obtained by several ply construction.

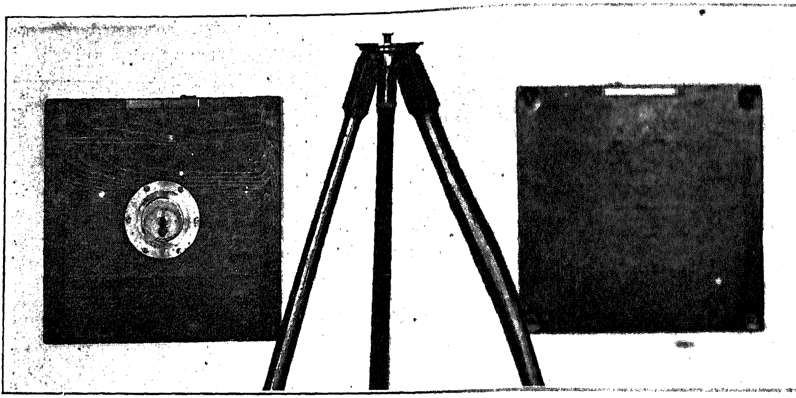


FIG. 33.—The small plane table with compass.

It is highly desirable that at least the corners, preferably the middle of each side also, be equipped with depressed brass screws and sockets by means of which the paper can be firmly attached to the board without the use of thumb tacks and without leaving anything projecting above the surface of the top which might interfere with the free movement of the alidade. Standard sizes of table tops range from 15 by 15 to 24 by 30 in.

The compass may or may not be attached to the table top. In most instances in oil work it is attached to the base of the alidade. The advantages of having it attached to the right or or left side of the table top are: first, that one can always see at a

glance whether or not the table is properly oriented; and second, that there is the saving of a little time in orientation. Most instrument men will recall that occasionally they have forgotten to complete the orientation of the table or have failed to note that it had been changed accidentally.

The chief disadvantage of having the compass attached to the edge of the table top, especially where the declination is as large as 6°, is that the land lines are noticeably not parallel to the sides of the paper, a condition which is not convenient in sectional mapping and not pleasing to the engineering eye. Another disadvantage is the difficulty of accurately replacing a worn and used sheet on the table. Since the control line is the needle itself, the sheet must be so replaced as to give the correct angular relation between the line of the needle and the land lines. This condition arises when, after a sheet has been removed from the table, it is found desirable to continue on it the work started there.

In case the needle is attached to the alidade, the land lines may be conveniently made to have any desired relation to the edges of the paper; the paper can be taken off the table and replaced without reference to its former position; and the compass will usually receive a little better care than when attached to the table. The disadvantages of fastening the compass to the alidade are that a little time is lost in placing the straight edge of the alidade parallel to the magnetic reference line each time the table is to be oriented or its orientation tested, and that in most instances the compass interferes with the free use of the vernier screw.

For those tables with attached compass, the needle is about 4 inches long and the needle box only of such width as to permit of the reading of 3° on each side of the zero point.

The tripod is constructed of well seasoned hard wood so as to be strong and yet light. The top is fastened to it by various methods, the chief essentials being ease and firmness of attachment, ease and adjustability of rotation of top, and lightness. Because of their weight, screw leveling heads are not often used

in oilfield work, the larger tables being equipped with special leveling devices such as the Johnson movement[1] or with adjust-

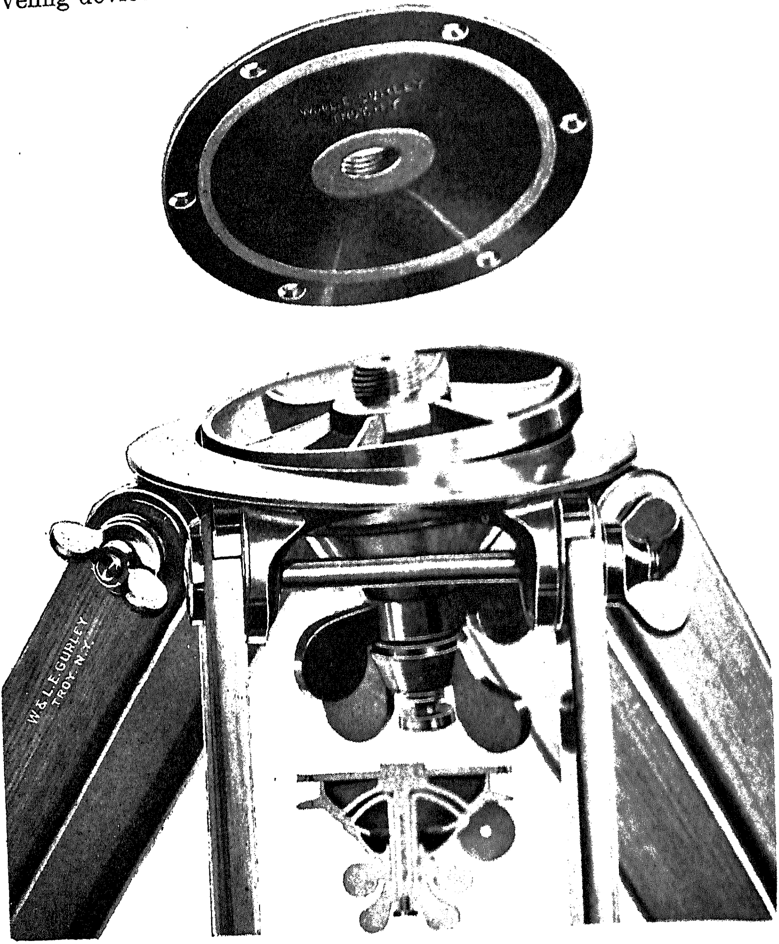


FIG. 34.—Johnson plano table movement and split leg tripod. (*After Gurley.*)

able skeleton legs, preferably the former. These increase the

[1] Invented by W. D. JOHNSON, of the United States Geological Survey.

weight of the table somewhat but add greatly to the steadiness of the top and to the ease with which it is leveled. The Coast and Geodedic Survey have also developed a special type of table.

The Johnson movement (Fig. 34)

"is essentially an adaptation of the ball-and-socket principle, so made as to furnish the largest practical amount of bearing surface. It consists of two cups, one set inside the other, the inner surface of one and the outer surface of the other being ground so as to fit exactly. The inner cup is in two parts, or rather consists of two rings, one outside the other, one controlling the movement in level and the other that in azimuth. From each of these rings a screw projects beneath the movement, and upon each of these screws is a nut by which it is clamped. There is no tangent screw for either the leveling or the azimuth motion, as none is required."[1]

Other things being equal, the larger the top the more unsteady it is, especially under the windy conditions which characterize the high, barren points commonly chosen as the best places for instrument stations. Therefore the use of smaller tables is often to be recommended, and special equipment is then not so essential; but in nearly all cases, whether the top is large or small, the Johnson movement is well worth while.

The chief care of the plane table consists in protecting the compass, if it is attached to the top; and in preventing injury to the bearing plate and the tripod head, because the latter is exposed and easily injured when the top is removed.

The plane table can be used to advantage in many kinds of areal mapping. Its chief advantage is that observations are placed directly upon the map with the saving of much time, and with the avoidance of those inaccuracies frequently resulting from the recording of data and its later transfer to the map.

PAPER

Paper is a compact mat of vegetable fibers. While there are some 400 varieties of fibers that can be used for this purpose,

[1] Gannett, Henry, Manual of topographic methods, 1906.

writing and drawing papers are made largely from linen and cotton rags.

"Good drawing paper must combine many different features, and these the buyer should be able to distinguish, to be in a position to discriminate between various kinds, so as to make a selection suitable to the purpose for which he intends to use the paper.

"First in importance is the material from which the paper is made, and second the mode of manufacture, both of which become manifest when the finished article is used. Good drawing paper should be strong, of uniform thickness and surface, stretch evenly, and should neither repel nor absorb liquids. It should admit of considerable erasing without detriment to its surface, should not become either brittle or discolored by reasonable exposure and age, and should not wrinkle when stretched or when inks or colors are applied to it.

"It is impossible to combine all these features in one paper, so that all may be apparent in their utmost degree of perfection; thus, the greatest strength cannot be combined with the finest surface, as is particularly exemplified in the case of manilla fibre, which, although one of the strongest materials used in the manufacture of paper, cannot be made into *drawing* paper.

"The careful draftsman is therefore compelled to select that paper which unites to best advantage those qualities which are the most adapted to his special requirements. To make a personal selection every time he is in need of paper is generally impracticable. He is therefore mostly obliged to rely upon the descriptions of the papers offered him, and then to trust that the one selected will be as described and can be obtained again in the same quality at any future time."[1]

Because of their fiber construction papers expand and contract differently in different directions and may not resume their original condition when the moisture is removed. Such changes may result in serious errors in case of very accurate work; but in oilfield mapping the chief objection to unequal shrinkage and expansion lies in the fact that the paper lies loosely upon the table top and is difficult to work upon. To counteract this tendency two or more thicknesses of paper, or paper and cloth, are mounted together with the direction of the longer dimension

[1] Keuffel and Esser Co., Catalog, 1915.

of the fibers of one at right angles to that of the other. In mounting, the sheets are either compressed between rollers and dried by passing over heated rollers or they are stretched, mounted, and left to dry over a smooth, flat surface. The latter process is supposed to produce the better results. Such sheets are naturally rather thick and hard to roll, but objectionable shrinkage and expansion may be entirely eliminated by this means.

The larger the sheet, the longer the time it is to be in actual use on the plane table, and the greater the humidity changes to which it will be subjected, the more necessary it becomes to use mounted paper and to choose it carefully.

Either ruled or unruled paper may be used. Ruled paper, assuming that it is ruled to the proper scale, has some advantages in laying off distances and assists one in keeping in mind the relative position of the observer and the land lines and monuments. It is disadvantageous in that there is always more or less trouble in properly orienting the paper and in that the lines tend to obscure data, especially when recorded with a hard pencil. Most geologists and instrument men prefer unruled paper.

Ruled paper is generally printed in blue, yellow, or green, *i.e.*, in colors which photograph white. The object of this is that the drawing may be inked in and photographed without the lines showing on the finished print.

Contrary to what might be expected, perfectly white paper is not to be prefered for field work as it reflects the bright sun light in such a dazzling manner as to be objectionable. A light shade of gray shows the pencil marks nearly as well and is more pleasant to work upon.

Sheets of semi-transparent celluloid, one surface of which has been rendered dull or roughened so as to make it possible to use a lead pencil on it, have been used to a slight extent as a substitute for paper on the plane table. It was used to some extent by the Corps of Engineers of the army during the recent war and has also been used by a few instrument men engaged in geologic work.

While the use of celluloid has some advantages for certain

types of work it has a good many disadvantages which under ordinary conditions more than offset the advantages. Its chief advantages are that it is perfectly water-proof and that a single sheet can be used over and over again, since pencil marks can be readily washed off with a cloth moistened with gasolene. Furthermore it is possible to make blue prints directly from the field map if celluloid is used. The most important disadvantages in the use of this material are as follows: it never lies perfectly flat on the table; it is very susceptible to temperature changes; it is difficult to see pencil lines on the sheet especially if one uses a hard pencil, and a soft pencil will rub off; it is difficult to make clean erasures unless one has gasolene at hand; the use of a pin point will soon make a sheet worthless; and the first cost is high.

It is doubtful whether the possibility of making direct blue prints is of much value, especially in cases in which more than one field sheet is used in adjacent areas. The difficulty of handling probably more than makes up for any advantage derived, and by using transparent paper the same results can be obtained. However, in areas in which only one sheet is to be used it might be worth while to consider the use of celluloid. The fact that it is water-proof is no doubt of some advantage but even this is seldom of any great moment. When weather conditions are so bad as to require perfectly water-proof plane-table sheets it is generally impossible to do careful work with a telescopic alidade, as the lenses will get fogged in spite of everything one can do, and better results will be obtained if such time is devoted to office work. The fact that a sheet can be used a number of times is more than balanced by the greater initial cost.

Some of the difficulties in the use of celluloid can perhaps be successfully overcome. For instance, in erasing pencil marks it is convenient to fill a hollow metal penholder with gasolene and plug the open end rather tightly with cotton. The cotton will allow sufficient moisture to come through to make clean erasures and if a cap is placed over it when not in use it is not inconvenient to carry. Concerning the detrimental effects of

pin-marks on the celluloid, it has been found through experience that accurate work can be done without the use of a pin. Many instrument men never use one, relying merely on the eye to place the ruler of the instrument in position, but some time is lost thereby.

Everything considered, it is extremely doubtful whether celluloid offers any decided advantage over paper as a table covering, and it will probably never have any wide use except in those cases in which it is necessary to work during very moist conditions.

CHAPTER II

INSTRUMENT METHODS

In petroleum work the geologic examination must usually precede leasing, and is so closely related to the securing and giving of oil and gas leases that it necessarily partakes of the demand for haste. The large amounts of money involved require that the work be done with due care. It follows that the work must be carried on with the maximum rapidity consistent with a sufficient degree of accuracy. The first means towards this end is the choice of the best method. When the method involves the use of an instrument man, as is usually the case, the rate at which the work progresses is limited largely by the ability of the geologist who acts as rodman to cover the ground and to work out the conditions; and to a less degree by the delay caused by the instrument man in taking his observations. To the end that the latter may delay the geologist as little as possible, he should know all the practical methods of obtaining distance and elevation, the accuracy of each method and the time consumed by each, and should choose with this object in view. Among those he should know are the methods for locating points without the aid of the geologist.

DETERMINATION OF DIRECTION

In running traverses in oil field work, directions are determined, as a rule, in one of the two following ways. (1) The bearing of the given line of sight is taken by compass or transit, and expressed as so many degrees and minutes east or west of north (or more rarely of south). Practically all the compasses commonly used by geologists are equipped with a device for setting off the local declination (magnetic variation from true north)

in such a manner that the readings observed are in terms of the true, rather than the magnetic directions. The observed directions are then plotted, by means of a protractor, on the map. (2) In operations with a plane table and alidade, the table is first set up and oriented, then the alidade is so placed that its straight-edge bisects the known point, and it is then sighted upon the distant object. A line is thereupon drawn through the known station in the direction of the unknown point, this line being the desired bearing. In this manner the line is plotted directly upon the map without measuring its relation to the cardinal directions. Whether the bearings are true or magnetic will depend on whether the table was oriented to true or magnetic directions.

DETERMINATION OF DISTANCE

Pacing.—Approximate distances, sufficiently accurate for reconnaissance work, and in some cases satisfactory for detailed mapping, are often secured by pacing. The method consists simply of walking with uniform stride, and counting the steps. The degree of accuracy which may be expected varies with the character of the country, and is greater in open, level regions than in wooded or hilly ones. An experienced compassman in average hilly, wooded country may be expected to be in error not to exceed 2 per cent., as a rule, although under very bad conditions the error might be greater. Allowance must be made, of course, for variation of stride in going up and down hills and through thick brush. It is here that experience counts for most in pacing.

The standard pace, which is supposed to represent the stride of the average man, is 2000 to the mile. Some advise an effort to conform to this step; others believe greater accuracy can be secured by using the natural stride, and determining over a measured course, the number of steps used per mile. It must be borne in mind that the natural stride varies between early morning, when the worker is fresh, and late in the day when he is tired; with the slope of the surface; with the obstructions en-

countered, such as grass and brush; and with the firmness of the soil.

Some count each footfall; others count double paces, that is, each right, or left, footfall; still others count every fourth step. This is governed in part by the distance to be paced continuously, in part by the mapping scale, and in part is a matter of personal preference.

Ability to retain numbers and to count without giving the matter conscious attention, comes with practice. There are various devices for keeping count. Some conveniently note the hundreds by closing their fingers successively; others exchange small pebbles from hand to hand; and others use tally belts having loops that may be slipped for each hundred. There are also counting machines of various types that work by a pressure of the thumb. The pedometer is a device intended to avoid the necessity of counting. It is about the size and shape of a large watch, and is to be carried in the pocket. In it is a nearly balanced weight, that moves with each jar of the body as a step is taken, and this movement is recorded by the counting apparatus. The pedometer gives fair results where the country is open and level and the walking continuous. However, each movement of the body is recorded and counted whether a step is taken or not, and this fact renders the instrument useless under most conditions.

A variation of the pacing traverse is that of the horse pace. In moderately open country, excellent results can be secured by counting the pace of the saddle animal. The average horse has a stride that is very uniform in length. It is easily counted by the lurch of the saddle at each step, without looking. The number of steps to the mile must be determined by trial over a measured course. Single or double steps can be counted as desired.

When pacing is used only occasionally, it seems best to use the natural stride, obtaining its value by trial and keeping the length fairly uniform by constant attention when varying conditions are found. When extensive mapping is to be done by pacing,

it is advised that, unless one is of unusual stature, a pace of convenient length, such as 2000 to the mile, be chosen and strictly adhered to. A pace of 2.64 ft., 2000 to the mile, is slightly shorter than that of the normal stride, but it scales readily; is one that can be kept up throughout the day and when the mind is busy with other matters; and is believed to be no more difficult for the average man to learn than any other length. Since any regular stride is unconsciously maintained only through practice, it is but little, if any more, trouble to adopt a convenient one.

On gentle slopes it is customary to use longer steps to allow for the inclined distance; but on slopes which are steep one of a number of methods may be used. Some simply estimate the horizontal distance from the top to the bottom of short slopes, some attempt to avoid error by lengthening their stride, some learn to drop every third or fourth step according to the steepness, others use a combination of methods.

Buggy Wheel Traverse.—Another method of determining distance along roads or in open prairie country is by counting the revolutions of a buggy wheel. The circumference of the wheel may be measured and the revolutions per mile calculated, or they may be tested on a measured course. Estimated corrections must be made for going up and down hills. In general the method is more accurate than pacing, especially in level country.

If but little of this work is to be done, a rag tied to a spoke will serve to identify each revolution. If the work is extensive, an automatic counting device may be attached to the wheel.

Automobile Traverse.—In country which can be travelled in a car, distances can be determined closely enough for most purposes with a good speedometer which reads to tenths of a mile.

Intersection Methods.—The intersection or triangulation method may be used to locate many nearby points without the loss of the time and exertion that would be required of the rodman were he to go to them. It may also be employed for the location and checking of the position of the alidade with respect to known points, and for the location of distant stations which may be later used as control positions for more detailed mapping.

A good instrument man tries to get all the desirable, available information with the least possible expense of time and effort on the part of the geologist or rodman. Commonly he is left to his own resources to locate desirable but unessential features, such as houses, creeks, roads, etc., and not uncommonly for the location of necessary information such as wells and land lines. Such locations are made largely by intersection and are plotted directly upon the map without measuring.

At the first spare moment after each set-up, the instrument carefully sights upon and lightly marks the direction of such visible points as he desires to locate. At the next set-up the operation is repeated, the location of each point being determined by the intersection of two lines of sight upon it. Not uncommonly points on streams or roads are determined by the intersection of one line of sight with a fence or land line of known position. These are the common forms of triangulation in oil field work and are of greater service than many instrument men appreciate.

Resection is a form of intersection in which the position of the instrument or observer is determined by means of backsights upon known points. When using a plane table and a non-telescopic alidade, it is frequently convenient to set up the instrument at a desired point and locate one's position by the backward extension of lines of sight upon two or more known points. This requires that two known points of suitable angular position can be seen from the place to be located. With only two points known, it also requires that the table be oriented by means of the compass needle.

It is also possible, by means of three known points, all visible from the unknown set-up, to locate the table without orienting by the needle. This solution is known as the "three-point-problem," and may be found explained in any good text on surveying. It is not of practical use in petroleum mapping, and is not given here.

Location by resection alone is but little used with telescopic alidades because in obtaining the elevation, it is but little more

trouble to get the direction and distance also. Nevertheless sights on points which have been carefully located furnish a valuable and ready means of checking the position of the alidade, and, for this purpose, it is not necessary that the two points be visible from the same station. The first point may be sighted upon from one station and the second from another, each showing the component of the error of location of the instrument as referred to a line normal to the line of sight.

In Fig. 35, *A* and *B* are two points the locations of which are known, presumably determined by triangulation from stations whose positions are known to be correct. From station 69, a backsight on *A* gives a line which passes to the right of

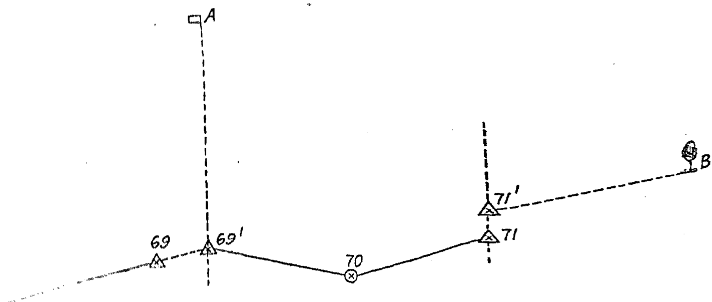


FIG. 35.—Method of correcting location.

the instrument station 69 on the map. If the position of *A* is correct, that of station 69 is wrong. If the error is permissible, the position of the station on the map is moved to this corrected line at 69′ in a direction either normal to it or in the continuation of the backsight on the previous station, the direction being determined by the best judgment of the instrument man, through his knowledge of the relative certainty with which the preceding sights have been taken. The work is continued until a point is reached, station 71, from which point *B* is visible. This gives a backsight line passing to the left of the instrument station 71 on the map. Having previously corrected the location for the direction of the line of sight from

A, the point on the map representing station 69 is moved parallel to that line of sight into the line of sight from *B*, at 71′ which completes the check.

Triangulation carried on by itself consists of measuring a base-line of known length and the location of points by the intersection of lines of sight from its two ends.

The length of a base-line may be determined by pacing, stadia, chaining, or such other measurement as is best adapted to the accuracy of the results desired. From point *a* at one end of this base line the bearing of an unknown point *c* is taken or plotted. This can be done with an alidade and a plane table, a transit, or a compass. In a like manner another line of sight upon point *c*, is taken from the other end of the base line, at *b*, and plotted on the map, this sight-line being prolonged to intersect the sight from *a*. The intersection of these two sight-lines will indicate the location of the unknown point. Its distance from either *a* or *b* can now be scaled from the map.

The accuracy of the method depends upon the accuracy with which the base line and the angles of bearing have been measured, and also upon the angle which the two lines of sight make with the base and with each other. For careful work the base-line is usually measured with chain or tape, and the angles or directions laid off with transit or alidade, while the angle of intersection of the sights with the base and with each other should not be less than 30°.

For less accurate work, or for reconnaissance, the base may even be measured by pacing, and the angles of the bearings by means of a compass. Almost any angle of intersection, however small, is preferable to simply estimating position.

Stadia Methods.—*Horizontal Wire.—Simple Intercept.*—The stadia wires of an alidade are usually so spaced as to intercept on a rod when held normal to them and to the line of sight an interval of 1 ft. for each 100 ft. the rod is distant from the anterior focal point of the objective. In measuring distance the operation is reversed, the intercept on the rod times 100 giving the distance. If the rod was always so held as to be normal to

the line of sight, the correct distance, whether horizontal or inclined, would be obtained, but this is not practicable. It is, therefore, necessary to make suitable corrections because the distance as ordinarily determined is only the approximate inclined distance and not the true horizontal distance which is usually desired.

In Fig. 36, the rod is represented by MN; the center of the instrument is at O, the anterior focal point of which is at F_1; and $(c + f)$ is the instrument constant. The observed intercept BA is greater than the true intercept ab so that to obtain

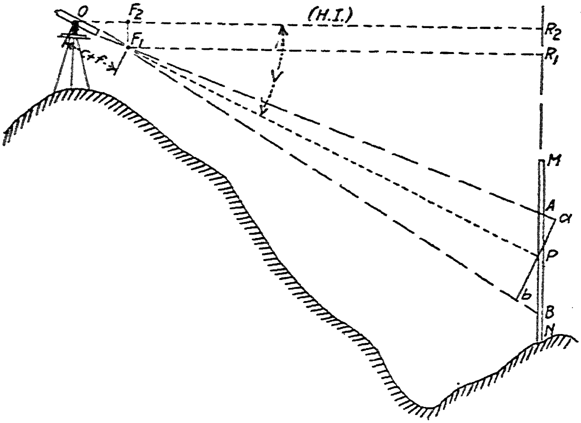


FIG. 36.—Showing reduction of apparent to true distances. (*After Bausch & Lomb.*)

F_2R_2 two corrections must be made, one because of too large an intercept and the other to reduce the inclined distance to the horizontal. These are made as follows:

The interval, AB, as read on the vertical rod, MN, is greater than the true interval, ab.

Let I = stadia interval, AB,
K = stadia constant, usually 100,
H = correct horizontal distance, OR_2,
V = correct vertical distance, PR_2.

Half-stadia Intercept Method.—Distances such that the legible portion of the rod is less than the stadia interval are usually obtained by reading one-half of the stadia intercept by means of the middle wire and one of the stadia wires. Such an intercept is multiplied by two for the full stadia interval. Thus a distance of 2800 ft. may be read from a 14-ft. rod. Here the error of reading is twice that of the simple stadia method so that the full stadia intercept should be read directly whenever possible.

Estimation Method.—Distance determinations by the simple and half-stadia methods cannot exceed 200 times the length of the rod; 2400 ft. with a 12-ft. rod, 3000 ft. with one 15 ft. in length. Commonly the lower foot or two of the rod is obscured by grass or other obstructions decreasing the distance to about 2100 and 2700 ft. respectively. The above method consists of first placing the lower stadia wire on the lowest recognizable point on the rod and estimating the distance the middle wire is above its top by comparing it with a known length of rod. The rod intercept plus the estimated distance should be a half-stadia interval.

This having been determined, the wires are moved until the top of the rod appears to bisect the distance between the middle wire and one of the stadia wires. This rod intercept when multiplied by four should give the stadia interval. If the two methods do not agree to within a foot, the observation should be repeated.

This method is quick and sufficiently accurate for many observations. It can be profitably used in part or in full with all instruments at times, but is chiefly valuable with instruments which have no gradienter screw.

Comparison Method.—If after placing the lower horizontal wire on the lowest visible point on the rod, the middle wire is above the top of the rod a distance not to exceed the length of the rod, this distance can usually be readily determined by noting the angle generated by this wire as it is brought to bear on the top of the rod and by turning off an equal angle in the same direction. The distance this wire is now below the top of the rod is

approximately the same as that which it was formerly above it. This distance added to the length of rod intercepted and multiplied by two gives the full stadia intercept. Providing the rod reading can be determined, this method is good for a distance 400 times the length of the rod (where $K = 100$).

The value of the angle is better determined in divisions of the gradienter screw as this is much more rapid than the reading of minutes, but care should be taken to eliminate any possible error due to back-lash in the screw.

Vertical Stadia Wire Methods. Vertical Rod.—This method may be used for sights so long that the half-stadia interval exceeds the length of the rod, in which case ordinary stadia readings cannot be taken.

After the instrument man has taken the necessary observations for the determination of direction and elevation, he rotates the telescope on its longitudinal axis until the stadia wires are brought into a vertical position, places the middle wire (now also in a vertical position) on the rod, and signals to the rodman the method he desires to use. The latter marks the point of the original sight and moves to one side at right angles to the line of sight until his rod as held in a vertical position coincides with one of the stadia wires. This having been determined, he measures with his rod the horizontal distance between the two points and later reports it to the instrument man. While greater accuracy could be obtained by using the other stadia wire in place of the middle one, alidades reverse the image so that it is very easy to get directions mixed and quite hard to rectify incorrect signals. By the use of the middle wire, it is immaterial to which side the rodman moves.

While somewhat involved and requiring a little more time than other methods, this would be ideal for obtaining the stadia interval for long sights, were it not for the fact that at those distances for which this method would naturally be used, it is impossible for the rodman to recognize with the unaided eye complicated signals. If the rodman is provided with a field glass and will keep it with him, this method may be used for any dis-

tance at which it is practical to take observations. It gives the correct inclined distance from the anterior focal point of the objective, and should be multiplied by the cosine of the vertical angle to obtain the true horizontal distance, but the fact that the distance is great almost determines that the angle is small and the correction negligible.

Horizontal Rod.—The correct inclined distance can also be obtained by observing a rod held in a horizontal position normal to the line of sight by means of the stadia wires rotated into a vertical position, but the cosine correction for horizontal distance must still be made.

Gradienter Screw Method.—It is possible to obtain distance by means of the gradienter screw since the intercept of a full revolution of the drum (two revolutions with some instruments) is equal to 1 ft. on the rod for each 100 ft. the rod is distant from the center of the instrument.

This method could be well used if the telescope had no stadia wires or if they were temporarily out of order, but is not used when either the stadia or half-stadia method is applicable because it is not so rapid and probably not so accurate, as there might occur a change in the position of the instrument between the two readings. Naturally, the optics of the central portion of the objective, as used by the gradienter method, are the better, but the stadia method has the advantage, in that both wires are under simultaneous observation and any deviation during the reading is, therefore, noticeable. However, the gradienter is a valuable means of determining distance when the visible portion of the rod as viewed through the telescope does not reach from one stadia wire to the middle horizontal wire. In all cases care should be used to avoid back-lash by turning the drum in the same direction to each reading.

This method gives the approximate inclined distance and is subject to the same correction as when determined by means of the stadia except that this distance is from the center of the alidade and does not involve a correction for the instrument constant $(c + f)$. The formula is

$$H = KI \cos^2 v.$$

Two methods are available: one in which the observer notes the space on the rod passed over by the horizontal wire for a rotation, or a convenient decimal fraction of a rotation, of the screw (the use of a constant drum difference or angle and a variable intercept); and the other in which he determines what part of a revolution is required to move the wire over a convenient length of the rod (a constant rod intercept and a variable drum difference).

The use of a constant drum difference such as 10, 20, 25, or 40 divisions (values chosen because of their simple relations to a full revolution, 100) facilitates computations. The method is objectionable for long sights in that it does not employ a maximum rod intercept, thereby increasing the error of observation; and it also necessitates that one be able to read or estimate closely any point on the rod that happens to be cut by the horizontal wire.

For short distances one has only to set the horizontal wire at the top of the rod (usually the point of greatest visibility and one permitting of the use of a maximum length of rod), read the drum, depress the line of sight one full revolution of the drum, and read the rod. In no case is it advisable to slip the drum on its shank in order that the zero may coincide with the index. The difference in the rod readings is the stadia interval.

At distances greater than 100 times the visible portion of the rod, a fraction of a rotation is used. After placing the horizontal wire at the top of the rod, the gradienter is turned down some simple fraction of 100 divisions, such as 40, $33\frac{1}{3}$, 25, or the like, using the largest of these which permits the wire to remain on the rod, and the rod is then read. The space on the rod moved over by the horizontal wire is then multiplied by the reciprocal of the fraction used (the reciprocals of $40/100$, $33\frac{1}{3}/100$ and $25/100$ are $2\frac{1}{2}$, 3, and 4 respectively). This gives the stadia interval.

Example 1.—With the horizontal wire at the top of the rod, the drum of the gradienter screw reads 27. When the screw is turned one full revolution in a direction to lower the line of sight and again reads 27, the wire has moved over 12.5 ft. on the rod.

The stadia interval is 12.5 ft. and the approximate inclined distance 1250 ft.

Example 2.—With the horizontal wire at the top of the rod, the drum reads 67. When turned to read 27[1] (40 divisions down) in a direction which lowers the line of sight, the wire passes over 10.7 ft. of the rod.

Since 40 divisions = 13.6 ft., 100 divisions = $^{100}/_{40}$ of 13.6 ft. = 34.0 ft., which is the stadia interval. The approximate inclined distance is 3400 ft.

Example 3.—With the horizontal wire at the top of a 15-ft. rod, the drum reads 3. When turned down to read $66\frac{2}{3}$ ($\frac{1}{3}$ of a revolution down), the wire cuts the rod 2 ft. above the ground or 13 ft. below the top.

$$\tfrac{1}{3} \text{ revolution} = 13 \text{ ft.}$$
$$1 \text{ revolution} = 39 \text{ ft. (stadia interval).}$$

Approximate inclined distance = 3900 ft.

With the *constant intercept method*, the observer first takes a drum reading on the top of the rod and then turns down to the lowest recognizable point of the rod or the rodman's person (or *vice versa*) and again reads the drum. This method is more accurate than the former as it uses a maximum length of rod, and it can be more often employed as it is not so essential that the rod design be legible, the observer using any two known points such as the top and bottom of the rod, or the top of the rod and some part of the rodman's person. The number of drum divisions corresponding to a known rod interval being known, the rod length equivalent to a full revolution, 100 divisions, can be computed. The computation is not so simple as in the first case but can be quickly obtained by the use of a table (Table IV, Appendix).

Example 1.—Drum reading at top of 15-ft. rod is 48 and at bottom 32.

$$48 - 32 = 16 \text{ divisions} = 15 \text{ ft.}$$
$$1 \text{ division} = {}^{15}/_{16} \text{ ft.}$$

[1] It is customary to construct alidades so that on elevating the line of sight the drum will read successively 3, 4, 5, etc. (and vice versa).

$$100 \text{ divisions} = {}^{1500}\!/_{16} = 93.75 \text{ ft. (stadia intercept).}$$

Approximate inclined distance = 9375 ft.[1]

Example 2.—The drum reading at top of a 15-ft. rod is 16. The bottom of the rod and the foot marks are not visible but the reading at the top of the rodman's leggings (known to the instrument man to be 1.5 ft. above the ground) is 94.

$$15 \text{ ft.} - 1.5 \text{ ft.} = 13.5 \text{ ft. (used length of rod)}$$
$$16 - 94 = 22 \text{ divisions} = 13.5 \text{ ft.}$$
$$1 \text{ division} = {}^{13.5}\!/_{22} \text{ ft.}$$
$$100 \text{ divisions} = 61.37 \text{ ft. (stadia intercept).}$$
$$\text{Approximate inclined distance} = 6137 \text{ ft.}$$

Vertical Arc Method.—The angle subtended at the instrument by the rod can be measured in minutes, but as this involves the time necessary for two arc readings, it is not used as a means of determining distance when more rapid methods are available. When using an alidade with stadia wires but no gradienter screw, the vertical arc may be conveniently employed to determine those distances which exceed the limits of the half-stadia interval method, *i.e.*, greater than 200 times the visible portion of the rod.

Our experiments indicate that in reading the vertical arc of small alidades with the aid of a magnifying glass the average error in reading is about 50″. This is 4.8 per cent. of 17′ 12″, a half-stadia interval. Considerable care must therefore be exercised to keep the angle as large and the reading as accurate as possible if the results are to attain even moderate accuracy, because the error of observation is approximately the same for large and small angles but is a much greater percentage of the latter than of the former.

As in the case of the gradienter screw, this method also affords the choice of a constant angle and a variable intercept or of a constant intercept and a variable angle.

The use of a *constant angle* does not materially simplify the computations, since seconds cannot be read or even estimated

[1] For rapid determinations of distance see Table IV.

with these alidades, and it is therefore impossible to use accurately full or simple fractional divisions of the stadia angle. Therefore, while the use of a constant angle necessitates that the rod be actually read or estimated, under average conditions and with a rod of high visibility, this method is probably quite as accurate as the use of a constant rod intercept and a variable vertical angle reading, perhaps even more accurate.

The use of 34′ in place of 34′ 23″ for the stadia angle or of 17′ for a half-stadia angle gives a value which is only 1.1 per cent. too small. If it is so desired, the result can be easily increased by this percentage of itself for the correction. The correct distances corresponding to vertical angles from 1′ to 17′ with rod intercepts from 6 to 15 ft. can be quickly secured by reference to Table V of the Appendix. To interpolate or determine the distance in cases in which the intercept involves tenths of a foot, increase the value read from the table for the integral part of the intercept, by an amount obtained thus: take the figures common to the columns corresponding to the observed angle and the 10-ft. intercept, move the decimal point two places to the left, and multiply by the number of tenths.

Example.—Suppose an angle of 11 minutes gave a rod intercept of 13.4 ft. In the horizontal column (table V, Appendix) for 11 minutes and the vertical column for 13 ft. are the figures 4063 ft. In the 11 minute and 10 ft. columns we find 3125 ft. Moving the decimal point two places to the left gives 31.25 ft., a value corresponding to an intercept of 0.1 ft. When multiplied by 4 tenths, this gives 125 ft., the value corresponding to an intercept of 0.4 ft. Then 4063 ft. + 125 ft. = 4188 ft.

Since it is possible to read the vertical arc to minutes, which correspond approximately to 1/34 of a stadia angle, this method can be used for sights much longer than can be taken by the ordinary stadia method. The distance determined is the approximate inclined distance from the center of the instrument, and is subject to a correction for horizontal distance.

Beaman Stadia Arc Method.—The first space on each side of the zero point (50) of the Beaman stadia arc is equal to the

stadia angle, 34′ 27″. Therefore it is possible to determine distance by sighting the horizontal wire on the top of the rod, moving the vernier to the zero point, and depressing the line of sight one division, whereupon the distance on the rod moved over by the horizontal wire gives the stadia intercept.

The distance refers to the center of the alidade but is otherwise subject to the same corrections as an ordinary stadia determination and is not so accurate. However, where the Beaman stadia arc is used to determine elevation, the correction factor shown on the H-scale is used to obtain the correct horizontal distance. (See pp. 58–59 and 120–122.) Since the smallest division of the Beaman arc corresponds to a whole stadia angle, this method cannot be used for sights longer than can be taken by the usual stadia method. While one can conceive of conditions under which this method may temporarily be of value, the writers have never known such to occur.

DETERMINATION OF ELEVATION

Aneroid Barometer

Methods of Observation.—In field work one should attempt to avoid pressure irregularities by a proper choice of method, and should apply such corrections to the results as are practicable and possible. Two general plans are followed; one method in which simultaneous observations are taken, one set being at a permanent station; the other method, in which but a single set of observations is required. The latter plan will be described first.

Single Observations.—This is the simplest and most common as well as the most practicable method of mapping small structures with slight differences of elevations such as characterize the Mid-Continent Field. Here observations are quickly taken over a series of stations, the results being checked by returning to the starting point or to some other point the relative elevation of which is known. (See bench marks, pp. 183–185.) The barometer may not check, or even in case it does check there may be irregularities of pressure that have come and gone, leaving

errors in the line of elevations, such as are shown to be possible by Fig. 37. In such a case repetition, especially if the observa-

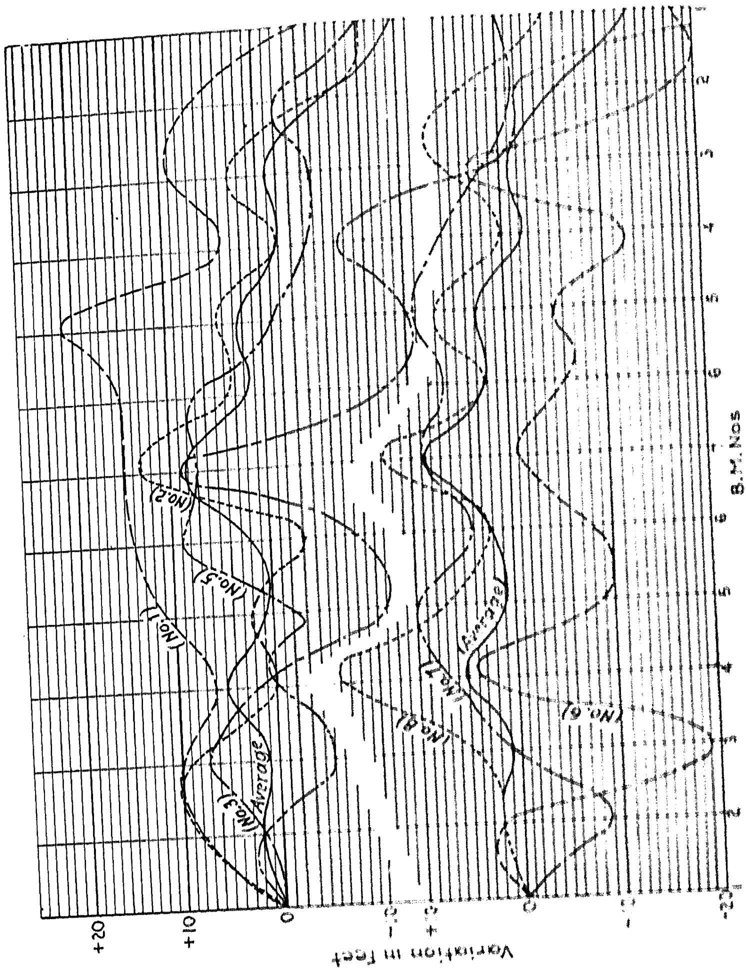


FIG. 37.—Apparent variation in atmospheric pressure as indicated by each of seven aneroids.

tions are taken in the opposite order will usually give fairly accurate results, providing the method and weather conditions

ANEROID READINGS AND COMPUTATIONS OBTAINED BY READING ALL[1] ANEROIDS AT EACH BENCH MARK. THE APPARENT VARIATIONS IN ATMOSPHERIC PRESSURE ARE SHOWN IN FIG. 37

Rolla, Mo.
Time: 1 to 4 P. M., Sept. 30th, 1915.
Weather: Slightly cloudy, light wind from the southeast.

Bench mark number	Elevation of bench marks	Difference in elevation	Aneroid No. 1		Aneroid No. 2		Aneroid No. 3		Aneroid No. 4		Aneroid No. 5		Aneroid No. 6		Aneroid No. 7		Aneroid No. 8		Average variation
			Barometer reading	Error	Barometer reading	Error	Barometer reading	Error	Barometer reading	Error	Barometer reading	Error	Barometer reading	Error	Barometer reading	Error	Barometer reading	Error	
1	1130	..	2094	....	1978	....	2272	....	2034	....	2013	....	2090	....	1978	....	1998		
2	1098	32	2070	− 8	1954	− 8	2242	− 2	1998	+ 4	1983	− 2	2060	− 2	1937	+ 9	1968	− 2	−2.1
3	1057	41	2031	− 2	1914	− 1	2206	− 5	1952	+ 5	1935	+ 7	1998	+21	1906	−10	1930	− 3	+1.0
4	1096	39	2066	− 4	1944	− 9	2240	− 5	2003	+12	1979	+ 5	2060	+23	1951	+ 6	1982	+13	+4.1
5	1015	81	1990	− 5	1865	− 2	2146	+13	1910	+12	1896	+ 2	1966	+13	1873	− 3	1890	+11	+4.1
6	1076	61	2054	+ 3	1925	− 1	2210	+ 3	1992	+21	1968	+11	2028	+ 1	1928	− 6	1946	− 5	+0.9
7	1101	25	2080	+ 1	1962	+12	2252	+17	2018	+ 1	1991	− 2	2060	+ 7	1958	+ 5	1982	+11	+7.3
6	1076	25	2055	0	1928	+ 9	2206	+21	1963	+30	1966	0	2030	+ 5	1930	+ 3	1946	+11	+7.0
5	1015	61	2000	− 6	1868	− 1	2143	+ 2	1930	−28	1897	+ 8	1970	− 1	1872	− 3	1890	− 5	−0.9
4	1096	81	2064	−17	1942	− 7	2231	+ 7	1986	−25	1975	− 3	2044	− 7	1950	− 3	1964	− 7	−5.3
3	1057	39	2030	− 5	1908	− 5	2176	+16	1939	+14	1935	+ 1	2020	−15	1906	+ 5	1931	− 6	−1.3
2	1098	41	2069	− 2	1940	− 9	2214	− 3	2006	+26	1979	+ 3	2040	−21	1944	− 3	1970	− 2	−5.3
1	1130	32	2090	−11	1968	− 4	2223	−23	2025	−13	2003	− 8	2072	0	1978	+ 2	1993	− 7	−7.4
Sum of errors			......	64	....	68	....	117	....	191	....	54	....	116	....	58	..	85	
Rank.............			......	3d	....	4th	....	6th	...	8th	....	1st	....	7th	....	2d	...	5th	

[1] Average variation omitting values of No. 4 which is obviously out of adjustment.

are favorable. Figure 37 shows that errors of twenty or more feet may occur in the course of a traverse, and still the barometer may "check in" rather closely at the end. Such errors can be detected in part by the operator, through a sense of difference in elevation which he gradually develops; by judicious use of the hand level; or by rerunning a traverse in case of doubt.

In general it is far better to have previously located the stations at which the elevations are to be taken, so as to make the time intervening between the starting and the finishing of a traverse as short as possible. In case it is necessary to stop at a station for more than the time required to take the pressure observation, the pressure should again be observed on leaving and the following elevations computed by differences. This eliminates such changes as take place while the observer is at the station.

The method of checking by repetition of observations in the reverse order is illustrated in the following table of aneroid observations.

TABLE OF ANEROID OBSERVATIONS

Going					Returning				
1	2	3	4	5	6	7	8	9	10
Station	Aneroid reading	Difference in elevation	Trial elevation computed forward	Trial elevation computed backward	Aneroid reading	Difference in elevation	Trial elevation computed forward	Trial elevation computed backward	Elevation
1	1846	....	1000	....	1840	+30	1002	1000	1000
2	1820	−26	974	....	1810	− 8	972	970	972
	1812								
3	1836	+24	998	....	1818	−30	980?	978?	998
						−14	996		
4	1850	+14	1012	....	1848	+ 8	1010	1008	1010
5	1842	− 8	1004	1002	1840	+30	1002	1000	1002
6	1810	−32	972	970	....	....	....	....	971

In the above example the barometer read 1846 ft. at station No. 1 at the beginning of the run. At station No. 2 it read 1820, indicating a difference in elevation between Nos. 1 and 2 of –26 ft. and an elevation of 974 ft. (column 4) for No. 2. So much time was comsumed at this point that the aneroid was again read before leaving, and was found to have changed to 1812. At No. 3 the reading was found to be 24 ft. higher than the last reading at No. 2, etc. After reaching No. 6, the observer returned, taking readings on the stations in the reverse order. These barometer readings for the reverse trip are similarly shown in column 6, the differences in column 7, and the trial elevations in column 8. Upon reaching No. 3 it was found that the last determination did not agree with the first one. Before going on to No. 2, the observer took time to discover that the first determination of difference in elevation between Nos. 3 and 4 is essentially correct. The entire difference between Nos. 2 and 4, thus proving the same in both cases, the corrected observation is accepted.

From the above data, four sets of elevations can be computed: two by the use of the initial barometer reading and the two sets of differences, and two by the use of the final reading and the two sets of differences. Only two of these columns, 4 and 9, are commonly used in determining the elevation (column 10) of the points. In averaging these, other things being equal, each is given a weight inversely proportional to the amount of time[1] that elapses between the reading of the aneroid at the point and at the bench mark. In the above case the two trial elevations in columns 4 and 9, except those for station No. 3, are of equal value, but it not infrequently happens that the observer knows one determination of a given point to be more accurate than another, and weights them accordingly.

Simultaneous Observations.—Part of the error due to pressure irregularities, especially those which are regional in their

[1] This does not include the time spent at a station if the aneroid is again read before leaving it, but only the time during which a change in the atmospheric pressure would influence the apparent difference in elevation of two stations.

extent, may be eliminated by the use of two observers. One plots the barometric changes against time at a nearby base station and the other takes pressure readings at the stations the elevation of which it is desired to obtain, noting in each case the time at which the observation is made. Each observation is later corrected by the amount of the barometric variation at the base station at that time.

This method does not eliminate irregularities which are local in nature and which are often the most troublesome, for such may not affect both stations and if so, not at the same time or to the same degree. The method is simple and of considerable assistance where rapid work is being done over a large area, for it does tend to eliminate the larger variations. The base station should be established as close to the place where the field observations are to be taken as is practicable.

Observations at a Selected Time.—It has been suggested that irregularities can be reduced by taking observations at that time of each day at which the *diurnal* gradient is supposed to be zero. While this method may be of value in certain kinds of work, it is obviously impracticable to limit geologic field observations to a single time each day, especially when the time must be first determined by trial. This method does not eliminate non-periodic irregularities.

Williamson's Method.[1]—This method differs from others in that a curve representing the average daily changes in pressure due to periodic irregularities is obtained by taking hourly observations, during a number of days. The greater the number of observations that are averaged, the more representative the curve should be. Field barometric differences in elevations are increased or decreased by the amount shown by the curve for that time of the day at which they are taken.

This method is an adaptation of the simultaneous observation method so that it can be carried on by a single observer. While it is not so accurate as the former, it is of value where approximate elevations of widely separated points are to be obtained by a single observer.

[1] WILLIAMSON, On the use of the barometer, pp. 39–42.

Summary.—There are other methods such as that of Whitney, of Plantamour, of Marshall,[1] of Ruhlmann, of Gilbert,[2] etc., but all fail to eliminate a considerable portion of irregularities. The latter methods require two or more observers and such an elaborate series of observations that the expense involved together with the loss of time and the remaining uncertainty of the results makes them impracticable for commercial work.

So far as is practicable, an observer should choose a method that avoids irregularities; corrections for such are always uncertain and only approximate at best.

Reduction of Inches of Mercury to Elevation in Feet

Pressures as read in inches of mercury may be reduced to feet of elevation by reference to Airey's table for the determination of altitudes (Table VII of the Appendix). These relations are for readings when the mean temperature of the atmosphere is 50° Fahrenheit. The temperature correction must be first applied if the mean temperature differs from this.

These are the values used in graduating the dials of surveying aneroids in terms of inches of mercury and in feet of elevation. The elevation as read in feet does not correspond to the elevation of a point as referred to sea level because the dial scale starts at a point some 800 or 900 ft. below sea level and because of the many variations in pressure due to causes other than difference in elevations.

Corrections for True Elevation

Correction for Temperature of the Instrument.—The various parts of an aneroid or a mercurial barometer expand and contract with changes of temperature, producing variations which, unless corrected, may influence the reading of the instrument. The variation in an aneroid for a given temperature change depends upon the size, composition, and relation of its parts. Most good

[1] U. S. Geol. Survey of the 100th meridian, Vol. II, p. 523.

[2] Report of the U. S. Geol. Survey for 1880–81, pp. 405–561.

aneroids are marked "compensated," by which it is intended to indicate that, owing to the use of metals with different expansion coefficients, the sum of the expansion and contraction of the various parts, in so far as they modify the movement of the index, is approximately zero, and consequently that no further corrections need be made. While such compensation is not complete, it is usually sufficient for any field work in which an aneroid is used.

In mercurial barometers, which are sometimes used at base stations, the changes due to the expansion or contraction of the mercury may be corrected by applying the following simple formula:

$H = h'[1 + 0.00008967\,(t_m - t_m')]$, in which

h' = the reading, either in in. or ft., at the upper station;

H = the height of the upper station corrected to the temperature of the lower station; and

t_m' and t_m = the temperatures of the mercury at the upper and lower stations, respectively.

The temperature is determined by means of an attached thermometer.

Correction for Temperature of the Atmosphere.—Since the air pressure varies with the temperature as well as with the elevation, determinations of the latter by means of the aneroid are complicated by changes due to the former. To eliminate such errors, the difference in elevation between two points as determined by barometric readings is multiplied by a correction factor. Surveying aneroids are commonly calibrated for a temperature of 50° F. In such cases the factor is,

$$1 + \frac{T + t - 100}{1000}$$

in which T and t are the temperatures in Fahrenheit degrees at the two points. If the temperature is expressed in degrees centigrade, the factor becomes

$$1 + \frac{9(T + t) - 180}{5000}$$

Other aneroids are calibrated for a temperature of 32° F., and the corrections for Fahrenheit and centigrade readings would be,

$$1 + \frac{T + t - 64}{900}$$

and

$$1 + \frac{2(T + t)}{1000}$$

respectively. Thus if D is the true difference in altitude between two points, the observed elevations of which are H and h, then we have,

$$D = (H - h)\left(1 + \frac{T + t - 100}{1000}\right) \qquad \text{(First case).}$$

Example.—Assuming altitude readings of 1650 and 1275 ft. and temperatures of 90° and 95° for the two stations,

$$D = (1650 - 1275)\left(1 + \frac{90 + 95 - 100}{1000}\right)$$
$$= 375 \times 1.085 = 407 \text{ ft.}$$

Both temperature and pressure readings are taken at each station, and the correction is generally made by the application of the above formula which assumes that the average of the temperatures of the two stations at the time the observations were taken is the average temperature of the vertical air column between the two horizons determined by the stations, irrespective of the horizontal distance between them. Obviously aneroid observations are made under the worst possible conditions and the average value for two stations but poorly represents that of the air column in question.

It should also be carefully noted that according to the above formula the error due to temperature is not eliminated when the temperatures of the two stations are the same, but only when their mean temperature is equal to that for which the barometer is calibrated.

The difference in the reading of a barometer due to a given temperature change varies approximately as the altitude. Thus,

for a change of 10°F. at an altitude of 100 ft., there is a change of about 2 ft.; for 1000 ft., 20 ft.; for 5000 ft., 102 ft.; for 10,000 ft., 204 ft.; etc. (See table VI, Appendix).

"For an error of 5°F. in the mean temperature of the level stratum of air between the two stations, the resulting error is approximately 1 per cent. of the difference of elevation. This error may, even under favorable conditions, be two or three times this amount, and under unfavorable conditions, five or six times as large."[1]

The temperature of the air varies more rapidly than that of the barometer so that the two should be determined by independent thermometers.

Correction for Humidity of the Atmosphere.—It is said that the amount of vapor in the atmosphere in temperate climates near the sea level produces a pressure which is equivalent to about one one-hundredth of the total barometric pressure. A correction for this may be applied as a separate formula or as a modification of the temperature factor. In any case the correction is small, made with difficulty, and of somewhat doubtful practical value.

Correction for Latitude.—The latitude factor is $(1 + 0.00260 \cos. 2\phi)$ and is due to the difference in the force of gravity at different latitudes. The correction is positive from 45° to the equator and negative from 45° to the poles. For a difference in elevation of 1000 ft., it varies from nothing at latitude 45° to 2.6 ft. at latitudes 0° and 90°, *i.e.*, a maximum possible error of 0.00260 of the difference of elevation. No correction for this is necessary.

Correction for Altitude.—This factor is likewise very small and need not be considered in this work.

Summary.—The only corrections that need be considered are those due to changes in temperature, to diurnal changes, and to irregularities of the instrument. All of these corrections are commonly omitted, having previously been reduced to a minimum by the choice of method. If an error of approximately one one-thousandth (one-tenth of one per cent.) for each degree

[1] Baker, I. O., Engineer's surveying instruments, 1893.

ahrenheit that the sum of the temperatures of the two stations xceeds 100° is permissible, the temperature need not be condered. Diurnal changes may be determined and the proper orrections made, but it is usually more expedient to avoid them. nstruments should be kept in such adjustment that errors in egistering the pressure are too small to be considered.

Hand Level

The hand level is commonly used to obtain the relative eleation of two points as a means of determining the general direcion of dip of rock beds or topographic slopes. The two points nay be alternately sighted on from a common point of view, but nore often the instrument is held level with one point and sighted pon the other.

It is also used to determine the difference in elevation of points. This difference may be the interval between two strata both of which outcrop on a given hillside, or that between an outcrop which cannot be seen from the alidade and a point higher on the illside which can be seen.

The first step is to determine the distance from the eye of the bserver to the ground and to stand in such a manner while ighting that this distance is always the same. Then, standing n the lower point, or, if that is not possible on a point of equal r known relative elevation, the observer picks out by means of he hand level a recognizable point on the hillside, at the same levation as his eye, preferably one near the shortest line joinng the two points. He then walks to this point and repeats the perations until the desired point is sighted upon. The result is number of intervals and a fraction such as 6 intervals less 3.5 t., the feet being estimated. If the height of the observer's ye above the ground is 5.5 ft., the difference in elevation beween the two points in this case is 29.5 ft. If the observations re carefully taken, and the horizontal distance is short, such leterminations are sufficiently accurate for all elevations other han those in the main line of alidade traverse.

It is evident that while one can back down the slope until the eye is level with the higher point, mark the point on which he is then standing, then back farther down and sight on that point, it is much quicker to start at the lower point and work upward.

As commonly used for quick sights, hand levels are fairly accurate, but in long sights greater than a quarter of a mile, the non-telescopic varieties cannot be expected to have an accuracy greater than 1 in 250. This is due in a large part to the area covered by the cross-wire at such distance, as well as to the varying position of the eye (parallax), and to the lack of sensitiveness of the bubble. If the instrument is steadied by something other than the unsupported hand, somewhat greater accuracy may be obtained than is otherwise possible.

Not unfrequently the geologist finds it desirable to use a hand level for sights much longer than was intended by the manufacturer. To this end the level should contain a lens segment which permits the cross-wire to be always in focus, the level must be carefully adjusted, and the hole in the eye end should be small, not to exceed a millimeter in diameter. It is admitted that when, as in sighting a gun, the sight is at such distance that the outline of the circle can be seen, the eye locates the center of the opening with a considerable degree of accuracy, but when the opening is so close to the eye that its limits cannot be seen, the parallax that may result from the use of an eyepiece containing a hole 2 mm. in diameter (a common size) may be very great on long sights.

The use of a rod with the hand level is very unusual and quite unnecessary in general, but where an accurate determination is desired, the hand level can be used in the same manner as an engineer's level. The observer moves a short distance in the direction of the second point and backsights upon a rod held vertically upon the first point. This reading shows how much higher his eye is than the point on which the rod is held. The rod is then held on the second point or some convenient intermediate point, and a foresight taken. This reading shows how much lower this point is than the eye. Knowing the actual distance

each point is below the level of the eye of the observer, their relative elevation is quickly determined as the difference. The observer may now go beyond the second point sighted upon, take a backsight on it, then a foresight on a third point, and determine the elevation of the latter with respect to the first and second points. With this method the distance of the observer's eye to the ground is immaterial so long as it is the same for a given backsight and the correspondnig foresight or sights.

In regard to the accuracy obtained by this method Keuffel & Esser state that "trials have shown that an accuracy of plus or minus 0.3 ft. in 100 ft. may be expected. This corresponds to about 1 to 2 ft. per mile."[1] Such accuracy can be obtained only by very careful work with the use of a rod.

Telescopic varieties may be more accurate, as, when adjusted, they have no parallax, and the magnification by the eyepiece permits of the use of a smaller wire. Such instruments also have a greater variety of uses; *i.e.*, in making the signals of the instrument man easily read, and in assisting in the recognition of formations and dips at greater distances than would otherwise be possible. That they are not in more common use is due in part to their cost and in part to the fact that in much of the work the benefit to be derived is not sufficient to offset the inconvenience of carrying them.

Clinometer

While the clinometer is usually used only to determine degree of slope, by applying its edge to a dipping layer of rock or by sighting along it up or down the dipping plane, the angle of inclination so determined may be used in computing differences of elevation, if the distance between the observer and the observed point is known. The method is a crude application of the vertical angle principle used with the telescopic alidade. It is most commonly employed in military sketching with the "slope board."

[1] This is based upon the law of errors as determined by C. F. Gauss, $\mu_s^2 = \eta\mu^2$. Personal communication from Keuffel & Esser Co.

ALIDADE

In areas of gentle folding where the average dip is 10 to 30 ft. per mile, where the location of terraces is important, and where "closure" or "reversal" of "structures" is commonly 20 or 30 ft., seldom exceeding 100 ft., such determinations of elevations as are necessary for careful detailed structural mapping are almost exclusively obtained by the combined use of the alidade, plane table, and stadia rod.

The importance of the alidade for such work decreases with steeper dips, with larger "structures," with obstructed view, and with lack of stratigraphic "markers" or strata that can be recognized from point to point.

Simple Leveling Method.—While it is not practicable to obtain all elevations by simple leveling methods, there are always some sights in which the middle wire of a horizontal telescope cuts the rod. Where possible the elevation of a point is always obtained in this way since it is simpler, quicker, and less subject to error than any of the other methods. In backsights the rod reading gives the elevation of the telescope above the point upon which the rod is held and the "height of instrument," or "H.I.," is obtained by adding this amount to the elevation of the point. In foresights, the rod reading is the distance the point is below the "H.I." and the elevation of the point is determined by subtracting this amount from the value of the latter.

Stepping or Intercept Method.—It is possible to obtain the difference in elevation between the alidade and a point on a rod in terms of the stadia intercept. In moving one stadia wire to the position formerly occupied by the other, the horizontal wire will have moved over the rod a distance equal to the stadia intercept for that distance from the instrument.

In Figs. 38 and 39, *A*, *B*, *C*, and *D* show four positions of the horizontal and the stadia wires, the former being represented by the letter *b* and the latter by *a* (upper wire) and *c* (lower wire). *A*, represents the position of the wires when the telescope is horizontal; *B*, their position when, by means of the tangent

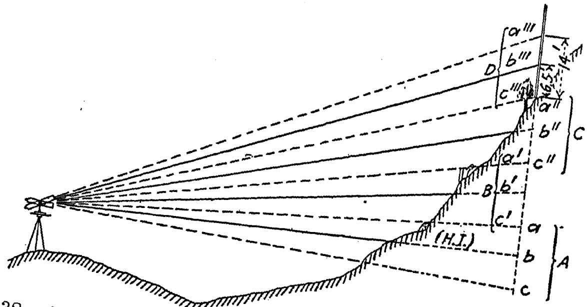


FIG. 38.—Determination of elevation by stepping method, side view.

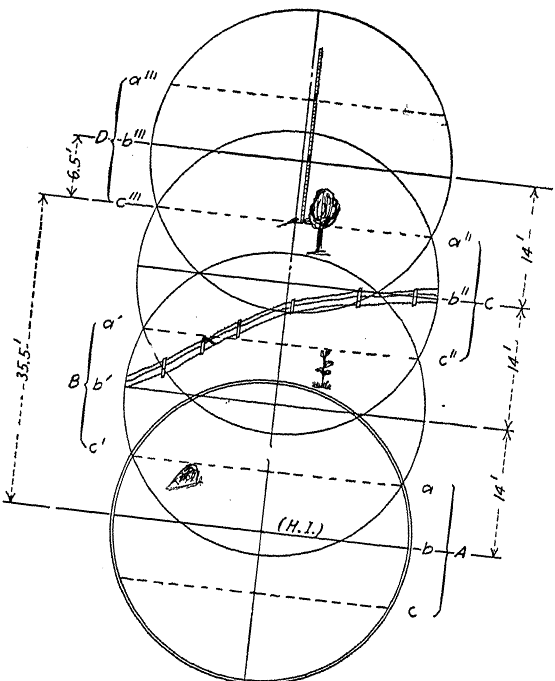


FIG. 39.—Determination of elevation by stepping method, end view. (*Modified after Bausch & Lomb.*)

screw, the line of sight has been elevated until the lower stadia wire, c, occupies the former position of the upper wire, a; C and D their positions after the operation has been twice repeated.

This is done by first carefully leveling the telescope and noting some recognizable point in the background cut by the upper stadia wire, shown as the top of a rock in the upper left hand quadrant of the lowest circle in Fig. 39. The line of sight is then turned up until the lower wire just cuts this point, c'. This is one step and the horizontal wire would intersect an extended rod at a distance equal to one stadia intercept above the height of instrument, "H. I." In a like manner a second step is taken by bringing the lower wire, c', to the position formerly occupied by the upper wire, a', the line being recognized by being at the top of a braced fence post and near the top of a certain weed. The horizontal wire would now intersect the rod, if sufficiently long, at a point twice the stadia intercept above the "H. I."

If, after three steps, position D, the horizontal wire intersects the rod at a point, b''', 6.5 ft. above the ground, and the stadia intercept is found to be 14 ft., it is seen that the point on the rod intersected by the horizontal wire is 42 ft. (3×14 ft.) above the "H. I." of the alidade, and the point on which the rod rests is 6.5 ft. below this, or 35.5 ft. above the "H. I."

If the sight is one of depression in place of elevation, the procedure is the same except that the line of sight is stepped down and the rod reading is added to the product obtained by multiplying the stadia intercept by the number of steps.

TABLE SHOWING PERCENTAGE ERROR IN STEPPING METHOD

Number of steps	Angle	$K \times \frac{1}{2} \sin 2v$	Discrepancy	Error in per cent.
1	34′ 23″	1.0001	0.0000	0.00
2	1° 8′ 46″	1.9998	0.0002	0.01
3	1° 43′ 09″	2.9987	0.0013	0.04
4	2° 17′ 32″	3.9969	0.0031	0.08
5	2° 51′ 55″	4.9926	0.0074	0.15
6	3° 26′ 18″	5.987	0.013	0.22
7	4° 00′ 41″	6.979	0.210	0.30
8	4° 35′ 04″	7.968	0.320	0.40

In determining elevation by means of the formula (number of steps) $\times$ (stadia intercept) $\pm$ (rod reading) = (difference in elevation), the stepping method is theoretically inaccurate because each step turns the line of sight through an angle the rod intercept of which differs from that of the preceding step. The accompanying table shows the theoretical error made by using the stepping method without corrections (p. 116).

The error for one, two, and three steps is too small to be considered; for four steps it is eight-hundredths of one per cent. A convenient rule and one which gives only a slight error for a small number of steps (the numbers most used) is to *decrease the result by a number of hundredths of one per cent. of itself equal to the number of steps times the number of steps when diminished by two.* Expressed in formula, Decrease expressed in per cent. =

$$\frac{(\text{number of steps}) \times (\text{number of steps} - 2)}{100}.$$

For example, per cent. correction $= \dfrac{4 \text{ steps} \times (4 - 2)}{100} = 0.08.$

Although theoretically inaccurate, as generally used for small angles this method gains in accuracy as compared with angular measurements because, as a rule, wire readings can be taken more accurately than the vertical arc or the Beaman stadia arc of small alidades can be read.

Computed Step Method.—The vertical angle having been determined and the stadia angle (34′ 23″) being known, the former may be divided by the latter to give the number of steps. The method avoids the necessity of having a good background but is otherwise subject to the same objections as the stepping method. The computations are as laborious as are those of the vertical angle method using a conversion table, and are not so accurate. They can, however, be made in cases in which the observer is not supplied with a table of stadia constants. This method should be used only as a temporary makeshift when another method is not available.

Vertical Arc Method.—As shown in the discussion of Fig. 36, the determination of distance by the use of the stadia intercept on a vertical rod is subject to two corrections; one because the

rod is not normal to the line of sight and therefore gives too great an intercept, and the other because the inclined and not the horizontal distance is obtained. As commonly used, the determination of elevation by the vertical arc involves the stadia intercept and is therefore subject to the same errors and corrections. To obtain the correct difference in elevation between the alidade and the point on the rod sighted upon when the angle is taken, the stadia intercept is multiplied by one-half the sine of twice the angle.[1] To simplify the computation, conversion tables may be carried which give this function of angles. (For convenience, some tables give 100 times $\frac{1}{2}$ sin $2v$.) (See table III, Appendix.) Special slide rules, known as stadia slide rules, are also manufactured, based on this function.

Example 1.—Assuming a vertical angle of $+ 3° 23'$, a rod reading of 10.0 ft., a stadia intercept of 12.5 ft., and a height of instrument (H.I.) of 1250.0 ft., we find the value of 100 times $\frac{1}{2}$ sin $2v$ (See table III, Appendix) to be 5.86 and 5.92 where v is 3° 22′ and 3° 24′ respectively. Therefore, by interpolation, the value of this function of 3° 23′ is 5.89.

$$\tfrac{1}{2} \sin 2v = 5.89$$
$$12.5 \text{ ft.} \times 5.89 = 73.6 \text{ ft.}$$
$$73.6 \text{ ft.} - 10.0 \text{ ft.} = 63.6 \text{ ft., difference in elevation.}$$

The above computation involves multiplication by a number consisting of three figures and the consequent loss of time and chances for error. Such computations interfere with the efficiency of the instrument man in that he cannot make the computations, check them, record the results on the map, and at the same time keep the rodman under constant observation and attend to his other duties. The instrument man therefore prefers to use more simple methods of computation and, where the vertical angle is much used, to employ a table which gives the computed results (See table III, Appendix).

Example 2.—Assume the vertical angle to be $+ 1° 24'$, the rod reading 15.0 ft., the stadia intercept 14.3 ft., and the height of instrument 1325.4 ft.; the approximate inclined distance is

[1] For the mathematical demonstration of this, see pp. 91–93.

then 1430 ft. By reference to table III of the Appendix, under 1° 24′ note that;

Difference in elevation for 1400 ft.	= + 34.2 ft.
Difference in elevation for 30 ft. (value for 300 with point moved one place to left)	= + 0.7 ft.
Angular difference in elevation	= + 34.9 ft.
+ 34.9 ft. − 15.0 ft. (rod reading)	= + 19.9 ft.
Elevation = 1325.4 ft. + 19.9 ft.	= 1345.3 ft.

The ordinary procedure in using the vertical arc is to sight the alidade on the rod, level the alidade, adjust the vernier to read zero angle, read the stadia intercept, sight the horizontal wire upon some convenient point on the rod, read it, "release" the rodman, read the vertical arc, and draw the line of bearing on the map.

This consumes an unnecessary amount of the rodman's time so that it is considered to be better to omit leveling the telescope and reading the vernier until later if the rodman is already on the point, or has been signaled "rod up."

The more rapid procedure then is; sight the alidade on the rod, read the stadia intercept, set the horizontal wire on some convenient point of the rod, read it, and "release" the rodman. While the rodman is going to the next station the vertical arc is read, the telescope leveled, the arc again read and the line of sight drawn on the table. The vertical angle is the difference in arc readings.

This makes a little more work for the instrument man but not infrequently results in the saving of time equal in value to the instrument man's wage.

If in taking a vertical angle reading the telescope is so set that the horizontal wire cuts the rod at a point equal to the height of the instrument above the ground, the line of sight is parallel to a line joining a point on the ground under the instrument with the point on which the rod is resting. The angular difference in elevation, the rod reading being omitted, gives the difference in elevation between these two points. Thus if the angle is always read with the horizontal wire cutting the rod at this point, the

rod reading need never enter into the computations of elevations. However, this method is not adapted to petroleum geology work because the rod cannot always be read at any desired point.

Beaman Stadia Arc Method.—The value of the angle as read in Beaman stadia arc divisions times the stadia intercept, which must also be obtained, is the correct difference in elevation between the alidade (H. I.) and the point on the rod cut by the horizontal cross-wire. It is usually desired to find the difference in elevation between the alidade and the point on which the rod is placed, in which case the value obtained above is diminished by the rod reading (point cut by the middle horizontal wire when reading the angle) if the line of sight is above the horizontal and increased by this amount if below it.

(Difference in elevation) = (number of divisions) $\times$ (stadia intercept) $\pm$ (rod reading).

There are no fractional readings on the Beaman stadia arc and it may therefore happen that, because of distance or partly obscured view, when the arc reads a full division the horizontal wire will not fall upon the rod. If either of the stadia wires intersects it, the reading of the horizontal wire can be computed by subtracting a half-stadia reading from the reading of the top wire or adding it to that of the lower wire. When no wire falls upon the rod, another method must be used.

The procedure with the Beaman stadia arc is as follows: the telescope is sighted upon the rod for direction, leveled, the index adjusted to read 50 (zero point), the line of sight turned up or down (as the case may be) until the horizontal wire approximately bisects the rod, the line of sight is then further moved until the index coincides with the nearest full division on the Beaman arc, the arc is read, the rod is read, the stadia intercept is taken, the rodman "released," and the line of bearing drawn on the map.

Any observation which includes a stadia reading is computed from the anterior focal point of the telescope and where great accuracy is desired the proper value for the instrument constant $(c + f)$ must be computed and added. (See pp. 91–93.) This is seldom necessary in geologic work.

Example 1.—Assuming the stadia intercept to be 14.5 ft., the reading of the V-scale to be 40, that of the H-scale to be approximately 1, and the intersection of the rod by the horizontal cross-wire to be 10.5 ft. above the ground, then

$40 - 50 = -10$, value of angle in Beaman stadia arc divisions;
-10×14.5 ft. $= -145.0$ ft.,

which is the difference in elevation between the instrument and the point on the rod. The negative sign indicating that the line of sight is below the horizontal, there results

$$-145.0 \text{ ft.} + (-10.5 \text{ ft.}) = -155.5 \text{ ft.},$$

which is the difference in elevation between the instrument and the station on which the rod is held.

Correcting for the true horizontal distance,

14.5 ft. $\times$ 100 (stadia constant) $=$ 1450 ft. the approximate inclined distance, then
1 per cent. of 1450 ft. $=$ 14.5 ft.,[1] and
1450 ft. $-$ 14.5 ft. $=$ 1435.5 ft., the true horizontal distance.

Example 2.—Assuming the stadia interval to be 9.5 ft., the Beaman stadia arc reading 60, the horizontal correction reading 1, the rod reading 5.7 ft., and not correcting for horizontal distance, then

$60 - 50 = +10$, value of angle in Beaman stadia arc divisions;
$+10 \times 9.5$ ft. $= +95$ ft., difference in elevation between instrument and point on rod;
$+95$ ft. $- 5.7$ ft. $= +89.3$ ft., the elevation of the station above the instrument.

[1] A horizontal correction is made only in case the amount is such as to show readily when plotted according to the scale used in mapping. That is, when mapping on a scale of 1000 ft. to the inch, one would not correct for less than 20 ft.

Example 3.—Assuming the half-stadia interval to be 14.5 ft., the Beaman stadia arc reading to be 52, and that only the top stadia wire cuts the rod where it can be read, the reading being 7.3 ft., then

$$14.5 \text{ ft.} \times 2 = 29.0 \text{ ft., stadia intercept;}$$
$$29.0 \text{ ft.} \times 100 = 2900 \text{ ft., approximate inclined distance;}$$
$$7.3 \text{ ft.} - 14.5 \text{ ft.} = -7.2 \text{ ft., horizontal wire reading;}$$
$$52 - 50 = +2, \text{ value of angle in Beaman stadia arc divisions;}$$
$$+2 \times 29.0 \text{ ft.} = +58.0 \text{ ft., difference in elevation between instrument and point on rod;}$$
$$+58.0 \text{ ft.} - (-7.2 \text{ ft.}) = +65.2 \text{ ft., elevation of station above instrument.}$$

Gradienter Screw Method.—In determining elevation by means of the gradienter screw the vertical angle is measured in terms of drum (gradienter screw head) rotations, each of which is equal to one hundred times the tangent of the angle. The difference in the elevation of the instrument and that of the point on the rod cut by the horizontal wire is the product of the horizontal distance and the tangent of the angle, or thè stadia intercept and the number of drum rotations. The difference in elevation between the instrument and the point on which the rod rests, is the above product increased or diminished (depending upon whether the sight is one of depression or elevation) by the rod reading.

Difference in elevation

$$= (\text{horizontal distance}) \times (\text{tangent of angle}) \pm (\text{rod reading})$$
$$= (\text{stadia intercept}) \times (\text{number of drum revolutions}) \pm (\text{rod reading}).$$

In turning the gradienter screw for an angle reading, it may happen that after one or more complete revolutions the horizontal wire or a stadia wire may still not have cut any visible

part of the rod, while another complete revolution will have carried the wires entirely past it. In such cases, a fractional part of a revolution is used. Obviously, the longer the rod, and the closer it is to the observer, the less probability will there be of such a necessity.

The use of full revolutions greatly facilitates the work as it is then only necessary to multiply the stadia intercept by a simple whole number such as 2, 3, etc., an operation which can be carried on mentally.

The general relations of distance to elevation involve the trigonometric functions of a right triangle of which the horizontal distance is the base, the difference in elevation between the alidade and the point on the rod cut by the horizontal wire the perpendicular, and the inclined distance the hypotenuse. The base (correct horizontal distance) times the tangent of the angle (number of drum divisions) gives the value of the perpendicular. The hypotenuse (correct inclined distance) times the sine of the angle also gives the perpendicular. The determination of distance as one hundred times the stadia intercept on a vertical rod gives neither of these but the approximate inclined distance and, as shown in the discussion of Fig. 36, should be multiplied by one-half the sine of twice the angle to obtain the true value of the perpendicular. However, the error involved by the use of the tangent in place of the above function is, for angles up to 10 revolutions or about 6°, much smaller than is commonly believed. The amount is shown by the accompanying table (p. 124).

A very close correction can be made by *decreasing the angular difference in elevation by a number of hundredths of one per cent. equal to the square of the number of revolutions of the drum.*

In comparing the accuracy of the gradienter screw with that of the vertical arc one should remember that the latter can be read with difficulty to the nearest minute, equivalent to 0.3 ft. in 1000 ft., while the former is easily read to one one-hundredth of a revolution, equivalent to 0.1 ft. in 1000 ft., *i.e.* the error in reading the vertical arc is about three times that in reading the gradienter screw.

Error Caused by Using Gradienter Screw with Stadia Intercept

Number of revolutions of gradienter screw	Value of angle	$K \times (\frac{1}{2} \sin 2v)$	Error in per cent.
1	34′ 23″	1.0000	0.000
2	1° 8′ 46″	1.9997	0.013
3	1° 43′ 6″	2.9974	0.086
4	2° 17′ 27″	3.9941	0.149
5	2° 51′ 46″	4.9882	0.235
6	3° 26′ 2″	5.9790	0.351
7	4° 00′ 14″	6.9653	0.497
8	4° 34′ 26″	7.9491	0.637

When properly constructed and in good working order, gradienter screws are sufficiently accurate for petroleum geology for the reading of all angles up to 7 or 8 revolutions, and furnish a very rapid means of determining elevation. It is recommended that they be used for nearly all small angle determinations.

Example 1.—Assuming that the stadia intercept is 13.2 ft., that the angle is 3 upward-revolutions of the drum (gradienter screw), and that the rod reading is 6.3 ft., then

13.2 ft. × 3 = 39.6 ft.
39.6 ft. − 6.3 ft. = 33.3 ft., difference in elevation.

Example 2.—Assuming that the stadia intercept is 10.5 ft., that the reading of the drum with the telescope in a horizontal position is 96, and that the reading of the drum when the line of sight has been turned down until the horizontal wire cuts the 10-ft. point on the rod is 61, then

96 − 61 = 35 divisions = 35/100ths of one drum rotation (stadia intercept)
35/100ths of 10.5 ft. = 3.7 ft.
3.7 ft. + 10 ft. = 13.7 ft., difference in elevation.

Stadia Wire Method.—In oil geology it is desired that the instrument work be carried on as rapidly as is consistent with the accuracy requirements. Permissible short cuts should always

be used. Among these is the reading of the rod intersection of one of the stadia wires when the horizontal wire cannot advantageously be made to intersect the rod. This can at times be conveniently used with all methods of determining elevation by the alidade except with the vertical arc, it being, in that case, always as easy and as rapid to set the middle wire at any desirable point as it is to set one of the stadia wires.

Since alidade observations consist of the determination of both distance and elevation, the former is always available in computing the latter. The distance, however determined, when divided by 100 (stadia constant) gives the stadia intercept, or the distance between the points on the rod cut by the stadia wires. From this it follows that the stadia wires cut the rod at a known distance (half-stadia intercept) from the point cut by the horizontal wire and that, conversely, the point cut by the horizontal wire is a half-stadia intercept above or below the point cut by the lower and upper wires respectively.

In the simple leveling, the stepping, the Beaman stadia arc, and the gradienter screw methods, the vertical angle has in general been laid off and determined before it is known whether or not the horizontal wire will intersect the rod. If it does not do so, but one of the stadia wires does, the reading of the intersection of the latter saves the time necessary to lay off a new known angle.

In using the stepping method a half-step interval gives no rod intersections that cannot be obtained by a full step, the lower or the upper wire simply being moved to the position formerly occupied by the horizontal wire. If, with one step upward the upper wire reads 3 ft. on the rod, one may record + 1 in the "V. A." column of the notes and U3 in the "Rod" column, or 1½ in the "V.A." and 3 in the "Rod" columns respectively. The first is preferred.

The Beaman stadia arc has no fractional divisions. It is much quicker to take a stadia wire reading than it is to make a new setting of this arc. Furthermore, at distances greater than 100 times the visible portion of the rod, it may be impossible to make

ERROR CAUSED BY USING GRADIENTER SCREW WITH STADIA INTERCEPT

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Example 1.—Assuming that the stadia intercept is 13.2 ft., that the angle is 3 upward-revolutions of the drum (gradienter screw), and that the rod reading is 6.3 ft., then

$$13.2 \text{ ft.} \times 3 = 39.6 \text{ ft.}$$
$$39.6 \text{ ft.} - 6.3 \text{ ft.} = 33.3 \text{ ft., difference in elevation.}$$

Example 2.—Assuming that the stadia intercept is 10.5 ft., that the reading of the drum with the telescope in a horizontal position is 96, and that the reading of the drum when the line of sight has been turned down until the horizontal wire cuts the 10-ft. point on the rod is 61, then

$96 - 61 = 35$ divisions $= 35/100$ths of one drum rotation (stadia intercept)

$$35/100\text{ths of } 10.5 \text{ ft.} = 3.7 \text{ ft.}$$
$$3.7 \text{ ft.} + 10 \text{ ft.} = 13.7 \text{ ft., difference in elevation.}$$

Stadia Wire Method.—In oil geology it is desired that the instrument work be carried on as rapidly as is consistent with the accuracy requirements. Permissible short cuts should always

be used. Among these is the reading of the rod intersection of one of the stadia wires when the horizontal wire cannot advantageously be made to intersect the rod. This can at times be conveniently used with all methods of determining elevation by the alidade except with the vertical arc, it being, in that case, always as easy and as rapid to set the middle wire at any desirable point as it is to set one of the stadia wires.

Since alidade observations consist of the determination of both distance and elevation, the former is always available in computing the latter. The distance, however determined, when divided by 100 (stadia constant) gives the stadia intercept, or the distance between the points on the rod cut by the stadia wires. From this it follows that the stadia wires cut the rod at a known distance (half-stadia intercept) from the point cut by the horizontal wire and that, conversely, the point cut by the horizontal wire is a half-stadia intercept above or below the point cut by the lower and upper wires respectively.

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In using the stepping method a half-step interval gives no rod intersections that cannot be obtained by a full step, the lower or the upper wire simply being moved to the position formerly occupied by the horizontal wire. If, with one step upward the upper wire reads 3 ft. on the rod, one may record + 1 in the "V. A." column of the notes and U3 in the "Rod" column, or 1½ in the "V.A." and 3 in the "Rod" columns respectively. The first is preferred.

The Beaman stadia arc has no fractional divisions. It is much quicker to take a stadia wire reading than it is to make a new setting of this arc. Furthermore, at distances greater than 100 times the visible portion of the rod, it may be impossible to make

the horizontal wire intersect the rod when the arc reads a full division. It follows, that if, after the angle has been laid off the horizontal wire does not cut the visible portion of the rod but one of the stadia wires does, its reading should be taken and the reading of the horizontal wire computed.

In using the gradienter screw there is less choice between taking a stadia wire reading or another full rotation as the latter requires very little additional time. It is quicker to take a stadia wire reading than it is to lay off a decimal drum reading, but when using the latter, it is best always to use the horizontal wire.

In all of the instances given, the computation of elevation differs in no way from that used when the reading of the horizontal wire is known, except that the position of the latter must be first computed from the position of a stadia wire, and, furthermore, the computed intersection may in some cases be below the point on which the rod is held, so that it is necessary to consider carefully whether its value is to be added to or subtracted from the angular difference of elevation.

Example 1.—If, with the telescope level, the lower stadia wire cuts the rod at 14.5 ft., the stadia intercept is 14.6 ft., and the height of the instrument is 1462.3 ft., then

one-half stadia intercept = 7.3 ft.
14.5 ft. + 7.3 ft. = 21.8 ft., rod reading for the horizontal wire.
1462.3 ft. − 21.8 ft. = 1440.5 ft., elevation of point.

Example 2.—If, after the line of sight has been turned upward 2 steps, the upper stadia wire reads 2.5 ft. (backsight), the stadia intercept is 11.2 ft., and the elevation of the point is 1227.0 ft., then

one-half stadia intercept = 5.6 ft.
2.5 ft. − 5.6 ft. = − 3.1 ft., rod reading for the horizontal wire.
(+2) × 11.2 ft. = + 22.4 ft., angular difference in elevation.

$+ 22.4$ ft. $- (-3.1$ ft.$) = + 25.5$ ft., difference in elevation.
1227.0 ft. $-$ 25.5 ft. $=$ 1201.5 ft., height of instrument.

This computation may also be made by considering this angle to be $+2\frac{1}{2}$ steps, and the horizontal wire reading 2.5 ft., whereby we have,

$(+ 2\frac{1}{2}) \times 11.2$ ft. $= + 28.0$ ft., angular difference in elevation.
28.0 ft. $-$ 2.5 $=$ 25.5 ft. difference in elevation.

Intersection and Vertical Angle Method.—Points may be located by the intersection method and their elevation determined by the use of the distances scaled from the map and the vertical angles as determined from one or both of the points from which the intersecting lines of sight were taken. Either the vertical angle or the gradienter screw method may be used, the computations differing from those already outlined only in that there is no rod reading (the horizontal wire being sighted directly upon the point) and the scaled distance is the correct horizontal distance, and not the approximate inclined distance as obtained by the use of the stadia intercept. The use of the tangent screw is therefore theoretically correct, and the tangent of the vertical angle should be used in place of the function, $\frac{1}{2}$ sin 2v.

Difference in elevation = scaled distance $\times$ number of drum divisions
= scaled distance $\times$ tan v.

The method is used both for the determination of the elevation of conspicuous points which need not be visited by the rodman, and for the determination or checking of the elevation of the alidade. It is of considerable value in both topographic and structural mapping.

There are many instances in the western states where the contact being mapped can be clearly seen for long distances. There are, therefore, many cases in which valuable time may be saved by the use of this method.

It not infrequently happens that there is within an area being mapped a prominent object such as a house, windmill, or silo,

which can be seen from many points. If this is located, by triangulation or otherwise, and the elevation of the top, or other prominent point, determined, the instrument man may, at any time it is visible, take an angle reading on it, scale the distance, and determine the relative elevation of it and the alidade, thus securing a check on his work.

Backsight Method.—It is possible and sometimes practicable to determine elevation by erecting a pole or flag of known position and elevation and backsighting upon it. If a graduated pole is used, the distance, if not too great, can be determined by a constant angle method, otherwise one of constant intercept must be used, *i.e.*, the height from the ground to the top of the pole or flag being known, the distance is computed by means of the angle which that height subtends at the instrument. If poles or flags are set at various section corners, elevation may be carried from point to point. The method can be used only in open country and is slow, as the plane table must be set up at the point of each observation. Its chief advantage is that it requires no rodman.

CHAPTER III

IDENTIFICATION OF STRUCTURE

GENERAL CONSIDERATIONS

Although a study of subsurface conditions, including water, number and character of sands, continuity of sands, the making of sand maps, and the like, are matters for the consideration of the professional oil geologist, they are determined chiefly in the office by a careful examination of the available well data, and are consequently not within the province of this work.

The field work of a petroleum geologist is confined largely, and in wild cat territory, almost wholly, to the working out of structural conditions of folding and faulting; in other words it is made up largely of a search for anticlines and terraces, and of the mapping of such areas.

An anticline may be defined as an arch in the rocks; as a structurally high point from which the rocks slope downward in opposite directions (Figs. 1 and 2). This slope may be, and frequently is, quite independent of the surface or topographic slope, so that an anticline may coincide with a valley or with a hill, and while a hill may be anticline, much more often it is not. In oil work, it is of the utmost importance to bear in mind that it is the dip of the buried rock beds that is to be determined, not the slope of the topographic surface, and that this information is furnished chiefly by the outcropping beds.

Some anticlines are completely closed, that is, the rocks dip outward in all directions from a structurally high point. In others, the dips are outward in only three, or even in only two directions. In the case of terraces (Fig. 6), the rocks have a dip in only one direction, but are much more nearly flat in certain places than in adjacent areas up and down the dip. In still other places the rock beds may be not only bent but actually

broken or dislocated in such a way that the broken ends of the same bed no longer meet. This constitutes a fault (Figs. 7–13). It is these conditions of direction and amount of dip and continuity of the rock beds that the field man in petroleum geology is concerned with and tries to indicate on his maps.

Where rock exposures are good and dips moderately steep, the recognition of an anticline in the field is a matter of compara-

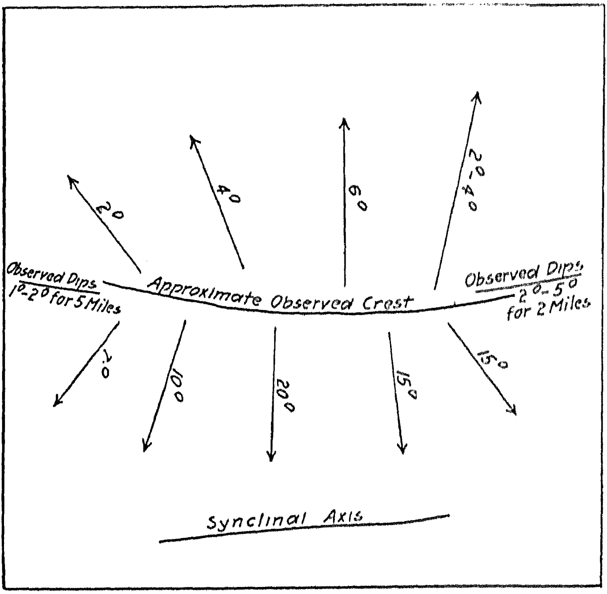


FIG. 40.—Type of reconnaissance map in areas where pronounced dips are the rule.

tive case, requiring but little training or experience. These cases, however, are the exception. Much more commonly the rock beds are poorly exposed or the dips are very low, or both; in which case it is only the trained observer who will note the changes in dip and then, perhaps, only after very close examination accompanied by instrument work.

Usually an anticline is so large or so placed that not all parts

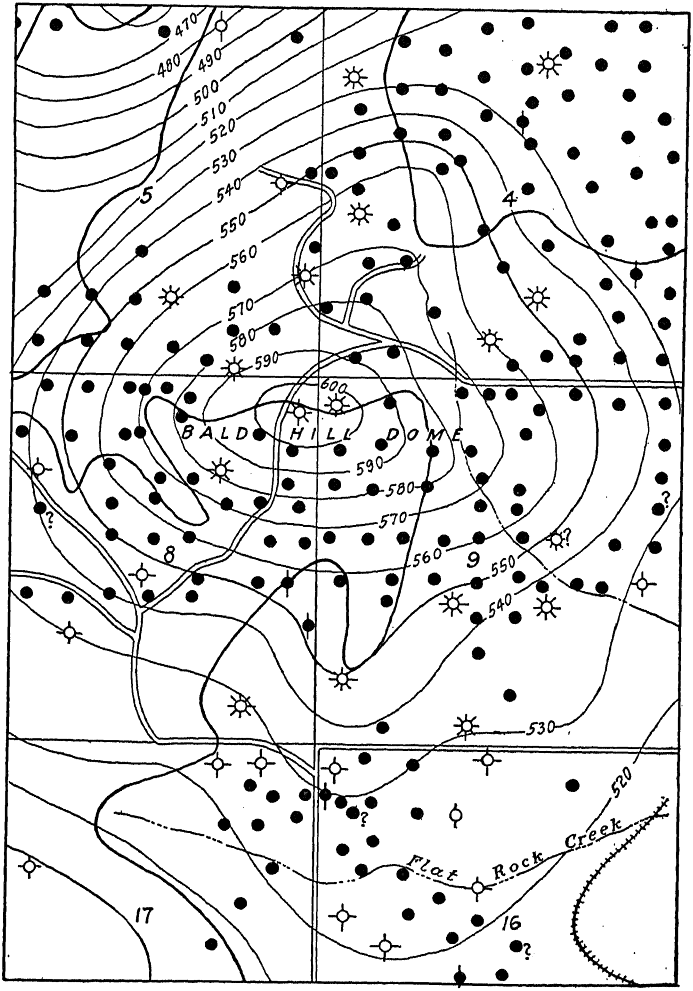


Fig. 41.—Structure contour map of Bald Hill Dome, Osage County, Oklahoma (*U. S. Geol. Survey.*)

of it can be seen at once. Observations of dip may then be plotted on a map as taken, the changes and relations of dip being more easily seen when thus assembled. The recording of the observations may be done in several ways. Where dips are sufficiently steep so that they are evident to the observer, arrows may be drawn in the proper position on the map showing the direction and approximate rate of dip as noted. (See Fig. 40). This is the method employed in much reconnaissance or geologic scouting work.

Where a detailed instrument survey is made, it is customary to take elevations at numerous points on outcropping beds, and to prepare a structural contour map. This consists of drawing lines through points of equal elevation on a given bed at constant intervals. The vertical distance represented between successive lines may be 5, 10, 20, 25, 50, 100, or more feet. Such lines are called structural contours, or isobaths, and the vertical distance between successive lines is known as the contour interval. Structural contour lines represent the surface of a given bed only; they delineate its form and indicate the size and shape of any fold present (Fig. 41). It is to be noted that these contours bear no necessary relation whatever to the topographic contours, which represent the surface of the ground.

IDENTIFICATION OF STRATA

Identification of strata, or stratigraphic correlation, presents many important and often perplexing problems. In so far as oil work is concerned, such correlations may be divided into three main aspects. The first and quite probably the one of least importance, is the determination of the geologic age, or the period and epoch to which a formation belongs; the second, the determination of the character and thickness of the underlying formations; and the third, the correlation, or the determination of the equivalency or non-equivalency of beds seen in separated areas, without reference to their geologic age.

Information concerning all of these can often be secured from geologic reports published by organizations such as the United

States Geological Survey, State geological surveys, and technical societies. But the geologist may sometimes be called upon to investigate and to render an opinion as to the probability of finding oil and gas in commercial quantities in some area such as parts of Wyoming, Utah, Arizona, or New Mexico, the general geology of which has as yet been but poorly worked out. To do this correctly, he must determine the geologic age of the surface formations and the general character and thickness of the underlying beds, and must map such structural features as are present, a work which will almost invariable involve the correlation of strata.

The geologic age of a formation may usually be determined from the character of the contained fossils, by a comparison of its fossils and lithologic characteristics with those of nearby formations of known age, or by actually tracing it into a formation the age of which is known. Some formations contain such peculiarly characteristic fossils that their identification is quite easy and positive, but more commonly such an identification will involve the collection of fossils by the oil geologist with the purpose of submitting them to a paleontologist for determination, many geologists not being sufficiently familiar with the highly specialized field of paleontology to make their own determinations.

Determination of age by means of lithologic resemblance is usually unsafe, as strata of widely differing age not uncommonly so closely resemble each other as not to be distinguishable. Yet there are formations which have such peculiar lithologic characteristics that correlation thereby for short distances is reasonably safe.

Not infrequently in deeply dissected or highly folded regions the approximate thickness and character of many of the underlying formations can be obtained from exposures in adjacent areas. Logs of deep wells, where available, are a valuable source of such information.

Much more commonly, however, an oil geologist is not so much concerned with determining the actual age of the surface rocks and the character of the underlying formations, a know-

ledge of these facts being already in his possession, as he is with the question of whether or not a bed on one side of a hill is the continuation of a similar-appearing bed on the other side. Inasmuch as structural maps are intended to represent the shape of the surface of a given stratum, it is obvious that in so far as this is determined by taking elevations from point to point, one must be absolutely sure that the points determined are on the same stratum or on one the stratigraphic relation of which to the former is known. There are instances in which a positive determination is impossible, but there are also many cases of incorrect correlation, even in the presence of abundant evidence. Errors in this respect have not uncommonly led to serious blunders in locating anticlines, not only by beginners but also by men of considerable experience.

There is no matter more fundamental in the mapping of structure, than correct identification of strata. Not only should the geologist be sure of his correlation, but in taking elevations care must be used to make certain that they are all taken on the same horizon of the stratum, preferably the top of a resistant member, since that is the plane most easily recognized, the base usually being buried beneath talus and soil. If a stratum is 20 or 30 ft. thick, very considerable error may be introduced by securing some elevations on its upper surface and others near its base. The top of a stratum is, of course, not the eroded surface, but the contact between it and the next overlying bed. Likewise observations taken above or along an unconformable contact may be entirely invalidated by erosion inequalities.

There are a number of significant facts that may be observed in the field to aid in correlation of beds. First and most important is the actual tracing of the formation from the one outcrop to the other. "Walk the outcrop" is advice that cannot be emphasized too strongly, especially for the beginner. This is advice of particular importance in detailing, where contour maps are to be made.

The walking of an outcrop is by no means a simple matter for in many cases it is more or less buried beneath a covering of

soil that renders its tracing difficult. In following a well-defined ledge that outcrops conspicuously, one not uncommonly finds that it apparently ends abruptly, and careful search fails to find it beyond the point of disappearance. Sometimes this is the result of faulting but in most cases it is not. The more conspicuous the ledge has been and the more abruptly it ends, the stronger the presumption of faulting. Such a supposition is still further strengthened by finding that the same ledge also ends abruptly on the other side of the adjacent valley, as is often the case. One should be cautious, however, in assuming faulting on unsupported evidence of this kind, since the stratum may "pinch out," or since changes in the thickness of the formation, in the degree of its resistance to weathering, in the steepness of the slope on which it occurs, or in the degree of exposure to sun, rain, and wind, may cause the outcrop to be buried for long distances.

Often where the ledge is not too deeply buried, the upper limit of "float" (fragments of the rock in the soil) may be followed in a definite line which indicates the position of the formation, but where a second, similar stratum occurs but little farther up the hill, the fragments from the upper outcrop may mingle with those from the lower, and make the tracing uncertain.

The character of the soil may also be of much help in tracing a buried formation. Soils from limestones, sandstones and shales are often quite distinct. One should study the soil conditions at points where the formations are well exposed, in order to learn the sort of soil yielded by each bed. The soil from very thin beds may be entirely masked by slump from the soils of thicker overlying beds, especially on steep slopes. Even where the physical characters of the soils are so similar as not to be easily distinguished, beds can sometimes be traced by the nature of the vegetation that grows on them. Even across cultivated fields, where there are no visible outcrops, and where few rock fragments can be noted, the trace of a formation can often be followed by differences in plant growth, sometimes by more abundant weed patches, sometimes by a scarcity of vegetation.

In sandstone areas traces of thin limestone beds can sometimes be followed for a long ways across fields by a peculiar and more luxuriant weed growth.

Where it is practicable to do so, it is often wise to "walk out" the outcrop of two successive limestones, checking the interval between them frequently for if the thicknesses and intervals of a series of several beds have been determined in two places, the fact of similarity of them all in similar order of succession, greatly strengthens the safety of the correlation. This is particularly to be recommended if one or the other of the beds outcrops poorly and is difficult to trace.

Where it is not possible, or is impracticable, to actually trace out the outcrop, other and less certain methods of correlation must be employed. One of the most commonly used is similarity of lithologic character. This must be employed with great caution in most cases. Marked peculiarities of the formation, such as the presence of chert nodules in abundance, fossils, oolitic character of the beds, black carbonaceous shale layers, coal seams, peculiar and unusual jointing in the formation, unusual color, and many other similar features, may be of great help. It must be remembered, however, that similar conditions of sedimentation produce similar beds, even at widely separated time intervals, and not infrequently an observer has correlated two outcrops on the basis of some peculiarity only to find soon after that some other bed above or below has the same peculiar features. Of course the greater the number of such features noted as being identical in two separate exposures the greater the degree of certainty in correlation.

While fossils may also be used for correlating beds, the average man in the field is not familiar enough with paleontology to name them scientifically, to distinguish between similar species, or to recognize their stratigraphic range, but merely uses the plant or animal remains as he might any lithologic character in comparing the beds. Even with the use of fossils it must be borne in mind that in a comparatively thin rock series containing several limestone beds separated by sandstones or shales, the fossil

forms may be recurrent, the same species occurring in several of the limestone beds, though absent from the intervening members.

The thickness of the formations should also be considered in correlation. Even though they were lithologically similar, one would hesitate to correlate two outcrops in closely adjacent areas if one outcop were much thicker than the other. This is especially true of limestones, which are much more constant in their thickness and physical characters than shales or sandstones, a fact following naturally from the conditions under which they were deposited. And yet a limestone, which has been carefully traced in outcrop, has been known to vary from 20 ft. in thickness to actual disappearance in a distance not much greater than half a mile. Such a rapid change in limestone is abnormal, however. Because of the much greater constancy of limestone in thickness and character, because it is less subject to cross-bedding, and because most limestones are more easily identified than other beds, they constitute much more satisfactory horizons on which to work than do sandstones or shales.

Usually, where a series of limestones dovetail into a series of sandstones, the limestone members all thicken consistently in one direction and thin consistently in the other. Cases are reported, however, where two limestone members, separated by a sandstone, change inversely, the one thinning in proportion as the other thickens. Such changes tend to invalidate thickness as a basis of correlation and yet thickness may be of help as a confirmatory factor.

In rapid reconnaissance work, distant beds are often correlated tentatively on the basis of color, continuous lines of vegetation, thickness, shape of profile of exposure, relation to number of prominent exposures above and below, or by other similar lines of evidences. If, however, one's observations of such a character lead him to suspect a favorable structural condition, these distant observations should be carefully confirmed, by using all the evidence available. While many such features are suggestive, long range correlation should seldom be allowed to pass as final where further expenditure in the area is recommended.

As previously suggested, elevations should be taken on the top of the stratum being traced, but in cases in which the bed is not actually exposed, this is approximately accomplished by using the highest fragments of "float." It is obvious that fragments are not above their source, except possibly in a glaciated region, and that where they are fairly abundant an elevation taken at their upper limit will probably be near the top of the formation from which they come; at least such an elevation when used with judgment may be of greater value than no elevation at all.

The contact may also be marked by a bench, where the softer overlying formation is worn back, and this bench is often visible, even where no rock outcrops. Care must be taken, however, not to confuse the top bench with minor local benches caused by soft local layers of shale or sand at varying horizons in the formation.

AVERAGE DIP AND METHOD OF DETERMINING SAME

Bedding planes are always more or less uneven, especially in the shallow water sediments which constitute the exposed formations of many of the petroleum districts. Clinometers are, therefore, seldom correctly used as contact instruments in dip determinations for in many cases such irregularities of bedding exceed the average angle of dip. In using a clinometer one may so stand or sit that his eye is on a level with the bed the dip of which is to be determined, and by sighting upon this bed at some distant point, determine the component of its dip in this direction. Where the line of outcrop is nearly normal to the line of sight from the observer, the straight-edge of the clinometer is held normal to the line of sight and approximately parallel to the line of outcrop. The lower the angle of dip and the more irregular the bedding, the longer should the line of outcrop sighted upon be, if the average dip is to be obtained. The clinometer is therefore held at such a distance from the eye that each end of its straight-edge is in the line of sight from the eye to one end of the visible portion of the observed line of outcrop.

These are the general methods of using the clinometr, ir-

respective of the angle of dip, and are used to advantage in either close or distant observations. They give only the component of dip in the direction observed, and not necessarily the true angle of dip. This is usually obtained with sufficient accuracy by interpolating between observations taken in directions normal to each other.

The value of angles of dip may also be determined by securing the relative elevation of a number of points on a given bed by means of a hand level, barometer, or alidade. Angles of half a degree or more can often be recognized by the unaided eye with sufficient accuracy for reconnaissance work.

VISIBILITY OF DIP

The angle of dip necessary that it may be recognized by the unaided eye depends upon the evenness of the bedding planes, the length of the outcrop, the adjacent topographic slopes, and the experience of the observer. Commonly, experienced geologists are able to recognize the direction of dip in slopes of one-third of a degree (30 ft. to the mile), even in comparatively short exposures of fairly well bedded formations. While the visibility of low dips is largely a matter of practice, it is often dependent upon the observer's ability to pick out the most reliable surface and to know just how reliable it is. Such ability is of maximum importance in sandstone areas where the beds are markedly irregular and cross-bedded.

The clinometer is used to aid the eye and to measure the amount of dips. By this means slightly smaller angles of dip can be determined than by the unaided eye and the determinations, in so far as the angular measurement is concerned, is definite. The accuracy of the unaided eye varies from day to day and is considerably influenced by the adjacent topographic slopes.

APPARENT DIP

In order to see the true dip in a distant exposed ledge, the line of sight must be practically parallel to the strike and the ledge

must be exposed in the direction of true dip, *i.e.*, at right angles to the line of sight. The edge of a steeply dipping bed, if seen in the line of strike only will appear to be absolutely flat.

Further than this, and more likely to cause errors of interpretation, is the fact that if the distant outcrop, which seems to be at right angles to the line of sight, be in reality oblique to it, a single component of the dip may be mistaken for the true dip. As an example, a north-east component of a true north dip might be, and frequently is, mistaken for an east dip. This is a common source of error on the part of beginners in reconnaissance work and should be carefully guarded against.

REGIONAL DIP

Over large areas of country, particularly on the flanks of important geologic uplifts, there is usually a low but dominant inclination of the beds in one direction for long distances, subject of course to minor variations both in direction and amount. This is known as regional dip. In the Kansas and Oklahoma portions of the Mid-Continent Field, the regional dip averages from 20 to 40 ft. to the mile in a general direction slightly north of west and is a result of the Ozark uplift. In eastern Colorado and western Nebraska, the regional dip is to the east, a condition caused by the Rocky Mountain uplift. About the Cincinnati Arch there is a general radial regional dip, outward in all directions from the structural center of the uplift.

One of the first things a man going into an unfamiliar field should do is to acquaint himself with the general direction and approximate amount of the regional dip. This he may do from maps, from reports, or by observation.

In a locality of west regional dip, any local area of east dip determines an anticline, Consequently in the Mid-Continent Field one hears much of "easts" or of "reversals." Any sudden change in the direction, or in the amount of dip, even though not constituting a reversal should be noted, as it may mark a terrace of importance.

AIDS IN RECOGNIZING STRUCTURE

Abnormal Regional Dip.—Oil fields are generally areas of well-defined regional dips, many of them doubtless owing their existence to this fact. Any further folding of such an area tends to increase the dip locally by the amount of that uplift. In general then, an increase in the angle of inclination of the beds beyond the regional normal probably means the near presence of either a reversal in the direction of dip, or a flattening of the angle of inclination, usually somewhere up the dip. Therefore a dip steeper than the normal, even though in the regional direction, suggests deformation and the probable presence of a possible oil structure.

In some cases an exceptionally steep dip may lead to a fault, in others, especially in Osage County, Oklahoma, where the regional dip is west by north a steep dip in the regional direction may occur just east of a syncline or structural depression without having east of it, in turn, a reversal or a decrease in the angle of the dip to less than the regional average. Here the corresponding anticline may be found directly to the west of the syncline, conditions being such as would result if the deformation had been caused by a sinking of the synclinal area rather than by the elevation of the anticline or dome.

Abnormal regional dip is an important criterion and its use has lead to the discovery of many structures. Changes in the amount and direction of inclination of the beds should always be investigated both up and down the dip if necessary, although the former is generally the more promising direction. Areas of abnormal regional dips are more promising and worthy of careful examination than those in which a preliminary reconnaissance shows only monotonous uniformity of dip.

Wavy Conditions.—In places one sometimes notes a wavy or rolling condition of the strata; a tendency for troughs to occur under the small valleys. Such a condition suggests local deformation and the possible presence of structural conditions worthy of investigation.

Fracturing.—Folding is instrumental in the formation of joints and small breaks or faults of a few inches or feet displacement. Other things being equal, the amount of fracturing should be greater where folding has taken place. Excessive jointing in limestone in the vicinity of folds is quite noticeable in some areas and "breaks" or small faults in limestone and sandstone are also often found. Such conditions are relative, but may indicate deformation and therefore suggest the possibility of favorable structural conditions.

Where, then, there is a minor wavy condition of the strata, or an abnormal condition of fracture, one should be particularly on

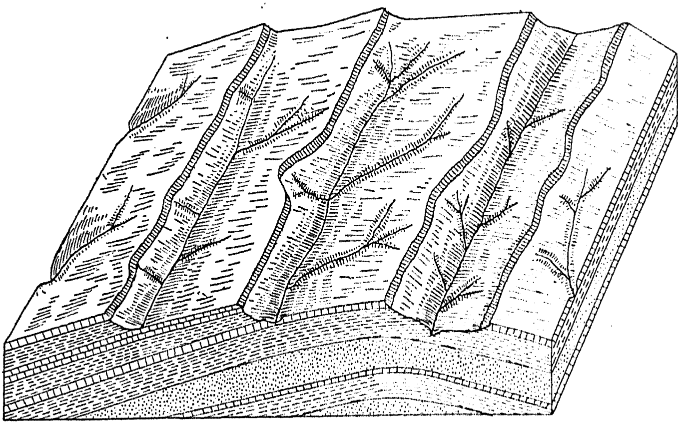


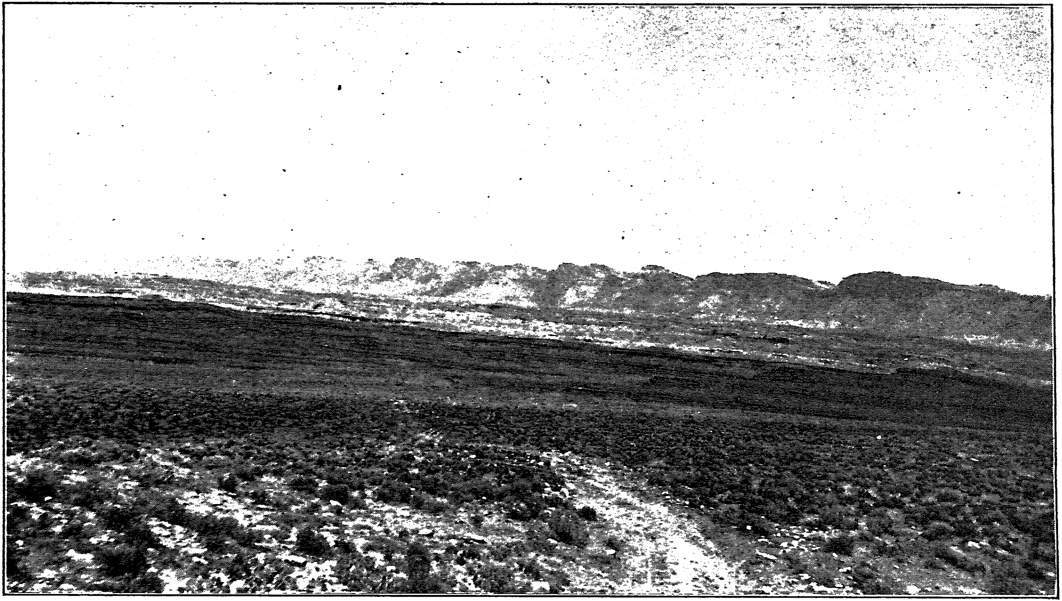
FIG. 42.—Block diagram showing relation of topographic features to dip of rock beds.

the watch, to learn the exact structural features responsible therefor.

Lines of Folding.—In many regions the folding seems to follow definite lines, in fact, this seems to be rather the rule in most areas. Not uncommonly, also, folds and faults are arranged en echelon, that is, in overlapping series, in such wise that the end of each overlaps slightly past the next. Consequently, areas in the direction of the regional strike from known structures are believed to be more favorable than others.

PLATE IX

Dip slope on surface of Pennsylvanian limestone, Big Indian structure, San Juan County, Utah.



Comb Ridge, an escarpment of La Plata (Jurassic) sandstone, on east flank of San Juan anticline, Utah.

Dip Slopes.—Dip slopes (Figs. 42 and 43, and Pl. IX) are those topographic slopes which parallel the inclined bedding of the rocks below. They are therefore a direct and often sufficiently accurate representation of the dip and strike of the underlying beds for the work at hand and one which can often be seen for long distances. Such slopes may or may not be present in a

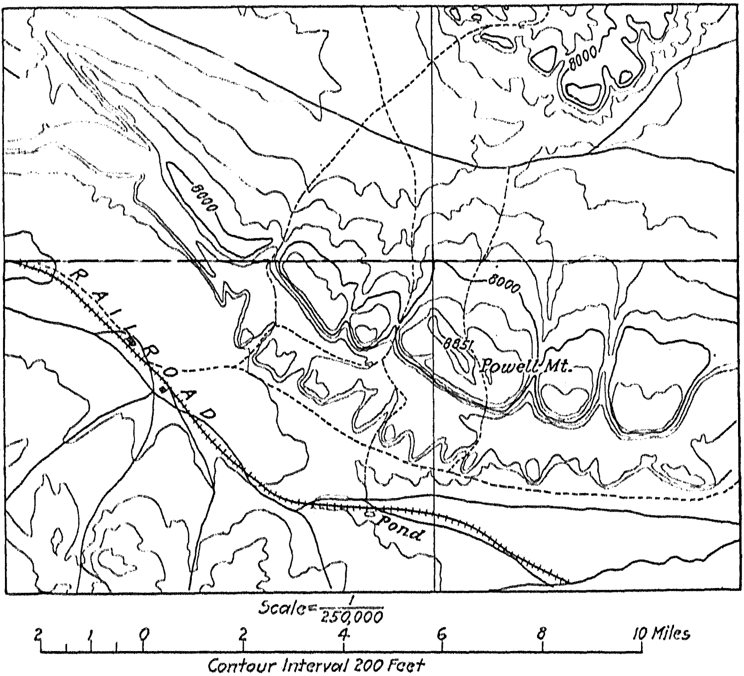


FIG. 43.—Topographic map showing cuesta with dip and escarpment slopes (Wingate sheet, New Mexico, *U. S. Geol. Survey.*)

given area and their value to the geologist increases with the lack of other determinative criteria and with the degree of certainty with which they can be recognized as such.

Thinly bedded, resistant formations, especially when made up of alternate layers of hard and soft materials, are best adapted to produce this feature. As degradation progresses the hills and

the valleys descend obliquely and retain the same relation to the beds. Where the dip of the strata is low, each of the more resistant beds tends to become the cap of a sloping plane (Figs. 42 and 43, and Pl. IX). The upper surface of a slightly inclined resistant stratum may be thus completely exposed and a dip slope formed. The erosion of limestone under these conditions will almost invariably result in the formation of dip slopes at the more favorable points, while the erosion of shale will almost never do so; or where such a relation does occur, it is accidental.

The profile of a hillside which has resulted from erosion of approximately homogeneous material has in general the shape of an inclined *S*, or better that portion of a sine curve which lies between an adjacent crest and trough. Starting at the nearly level hill top the slope gradually increases to a maximum midway down the hill and from there gradually decreases to zero in the valley. The eye of a trained observer becomes so accustomed to natural erosion features that deviations such as the nearly straight, though perhaps broken or interrupted profile of a dip slope (Figs. 42 and 43, and Pl. IX) are quickly noticed. This is the most important criterion for its recognition. It is apparent both in distant and in close observations and is of assistance in reconnaissance and detailed work. Such slopes are further characterized by the absence of seepages, by a scarcity of vegetation, by the relative readiness with which the vegetation burns out under the summer sun, and by the presence of thinly bedded pieces of float similar to the beds immediately below. Each of these characteristics may occur in all degrees of perfection and in some cases their combined evidence may only be sufficient to suggest but not to prove the presence of a dip slope. Here experience, and especially experience with development of dip slopes on the particular formations in question, is of great value. Under such conditions confirmatory evidence is carefully sought. This confirmation may consist of a graceful bending of the topographic contours such as to suggest the change in direction of dip of the beds around a structure rather than the

irregularities of erosion, or it may consist of actually observed rock dips.

It may then be repeated that long, abnormally straight, and slightly sloping topographic profiles, when seen at a distance, should at once arouse the attention, and where the inclination is not in the direction of the regional dip, should invite further investigation.

Inasmuch as the rate of erosion increases with the topographic slope, and since lateral wear is most important when the erosion is slow, it follows that erosion features are, as a rule, more representative of the structural conditions in areas of gentle topography than in rougher areas.

Erosion Escarpments.—The erosion of inclined or tilted strata gives rise to topographic forms which are characterized by their lack of symmetry. Where, as is generally the case, hard and soft strata alternate, the latter are rapidly eroded. On encountering a more resistant layer a stream not flowing in the direction of the dip is deflected against the side towards which the rocks dip. This causes the rapid erosion of the less resistant material and the sapping or caving of the more resistant beds forming steep, cliff-like forms known as erosion escarpments (Figs. 42 and 43, and Pl. X). On the other hillside such forms are absent and the contour of the hill dips gradually towards the stream and tends to be parallel with the bedding, that is, to become a dip slope.

Forms of this sort with well developed escarnment and dip slopes are commonly termed cuestas (Figs. 42 and 43). They are formed at all topographic elevations and usually in frequent succession, the escarpment of each usually capped with a layer more resistant than those below. Where the regional dip is constant and well pronounced over large areas, such escarpments occur at frequent intervals, facing in the opposite direction to the prevailing inclination of the rock beds (Fig. 42).

In the Oklahoma and Kansas portions of the Mid-Continent Field such eastward facing escarpments are very common. The Flint Hills of Kansas are very good examples. When well de-

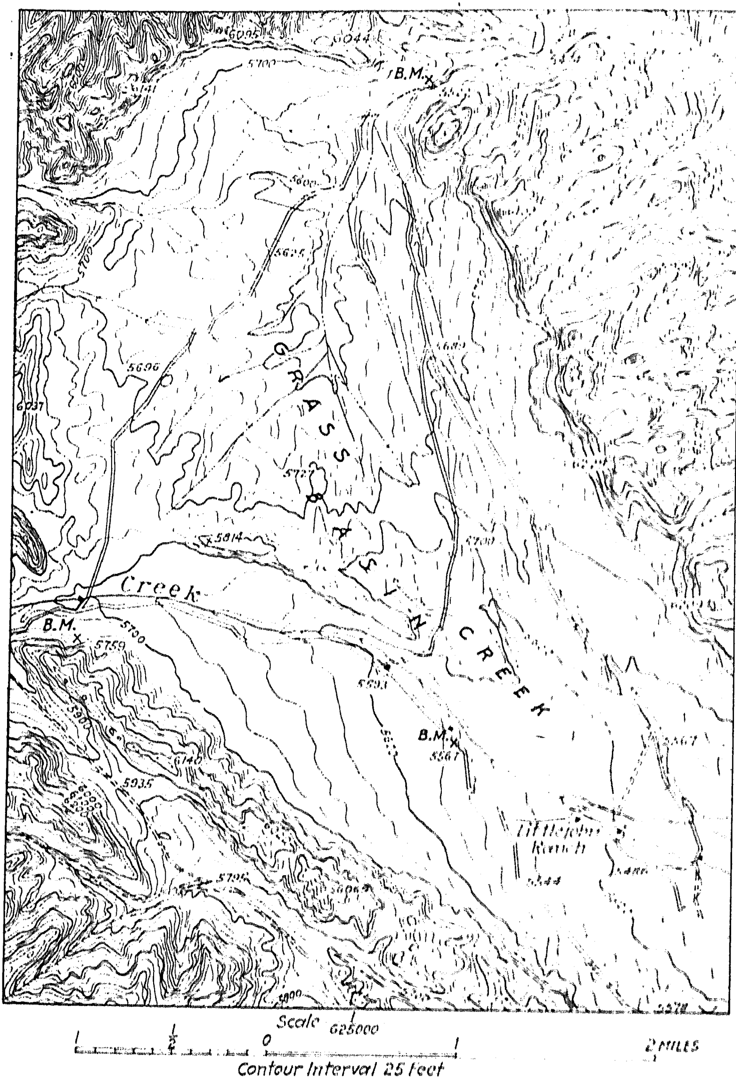


FIG. 44.—Dome with central basin and enclosing escarpment. (Grass Creek Basin, Wyoming, *U. S. Geol. Survey.*)

veloped, they are fairly positive in their significance. They are best viewed from a distance.

In a region of prevailingly east-facing escarpments any definite line of west-facing escarpments should at once arrest attention and suggest the possible presence of east dips. Such indications alone should not be taken as final, however, but should be confirmed by other evidence. In some of the western oil fields, where the rocks dip steeply, the folds are entirely enclosed by inward-facing escarpments or rims, with a central valley (Figs. 44 and 45).

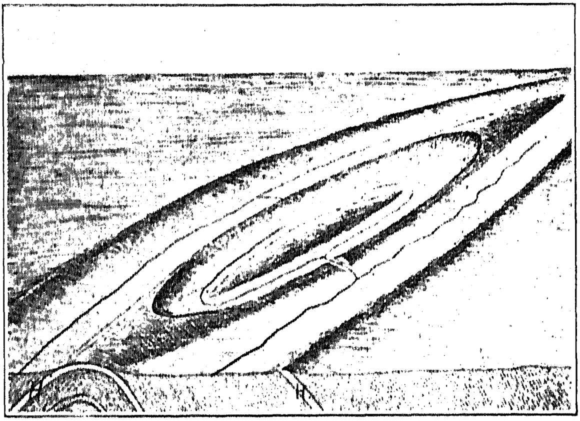


FIG. 45.—Diagram to illustrate the effects of erosion on a doubly plunging anticline made up of beds of unequal hardness. (*After Chamberlin and Salisbury.*)

Valley Profiles.—Longitudinal or strike valleys tend to have an unsymmetrical profile, one side being steep or nearly vertical and the other gently sloping, the latter being on that side in which the strata dip towards the stream (Fig. 42). This is a very general condition and one that can be readily noted in practically all oil fields. The side on which the dip is away from the stream is supported by the truncated edges of the resistant beds and is eroded largely by sapping. Its surface, therefore, tends to be steeply inclined. The side on which the dip is towards the stream

has less tendency and ability to form steep slopes. The inclined hard layer, and the more uniform erosion due to the larger amount of water from springs, seepages, and surface run-off, tend to plane this side down to a dip slope such as has already been described.

Only where hard and soft beds alternate are such structural features formed. The erosion of soft, homogeneous material gives little or no evidence of structural conditions.

Streams which flow in the direction in which the rocks dip (dip, or transverse streams) tend to cut steep-sided symmetrical valleys and the erosion criteria for the determination of dip is less pronounced in such valleys. Those which flow parallel to the strike of the beds (strike, or longitudinal streams) develop unsymmetrical valleys and show the best erosional evidence of structure.

A dominance of strike valleys having unsymmetrical cross section, indicates a regional dip, just as do erosion escarpments and dip slopes. In fact, such an unsymmetrical profile consists, at least approximately, of an erosion escarpment on one side and a dip slope on the other. If then, one finds in such a region a valley in which these relations of slope are reversed from the regional conditions, it should suggest, but not prove, a reversal of dip and should be given further investigation.

Topographic Highs.—As noted under erosion escarpments, drainage courses gradually work their way down the dip and farther and farther from the highest point structurally, although this condition is pronounced only in areas of alternating hard and soft rocks. If the beds dip in all directions from such a point, there is a very marked tendency for it to become one of topographic relief (Fig. 46).

Where local warping has taken place, the law, worked out by Campbell, is that erosion causes a divide to migrate towards an axis of uplift, away from one of subsidence. The coincidence of structural and topographic "highs" is therefore a natural condition and in the absence of other influencing conditions would always tend to occur. However, other influencing con-

ditions are not often absent and many structural highs do not correspond to topographic ones and *vice versa*. Whether or not such a coincidence will occur and the degree to which this feature will be developed depends upon many factors, prominent

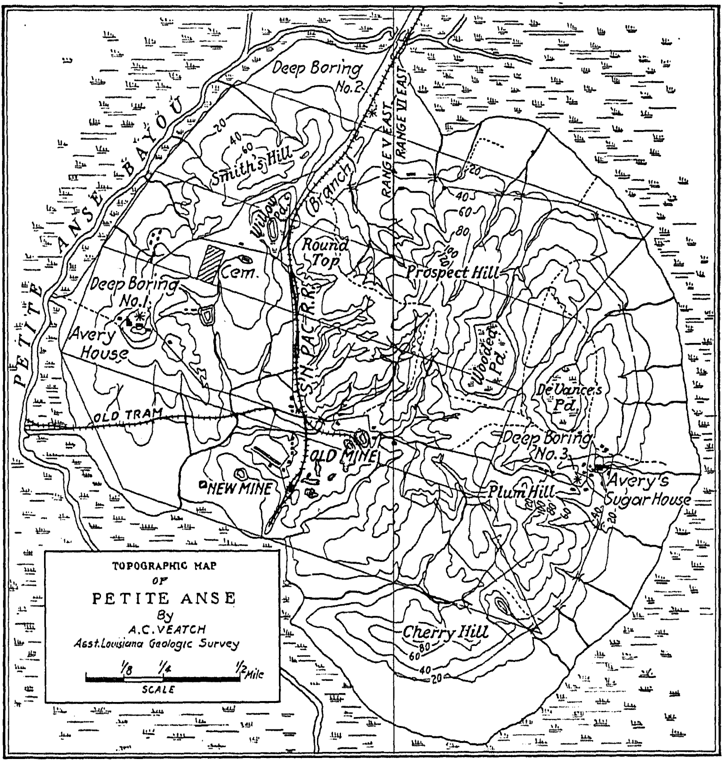


FIG. 46.—A salt dome, showing topographic high, with radiating drainage (Petite Anse).

among which are the presence of resistant beds to influence the erosion, as noted under dip slopes; the degree of folding; the amount of erosion; and the original position of the antecedent drainage courses.

The structurally highest points of many important folds lie

in valleys or at points topographically low, but topographic highs are to be considered favorable areas and should be given a closer examination than is given the average territory.

They are of particular importance in the Gulf Coast Plain, where the mounds marking the sites of the salt domes often constitute the only pronounced topographic highs for many miles (Fig. 46). Erosion has done comparatively little in this very immaturely dissected area, to destroy the topographic expression of structure. Likewise the structurally highest points of many anticlines of the Mid-Continent Field coincide with a gently rounded topographic elevation.

As the degree of folding and the angle of the dip of the beds increase beyond a certain point there appears to be less and less tendency for structures to be represented by topographic elevations, possibly due in part to the shattering effect such folding has upon the rocks at the crest and the consequent ease of erosion, and partly due to rapid erosion which permits of but little lateral wear. In such cases synclines may tend to become mountains and anticlines valleys. This is seen in the familiar "synclinal mountain" type of some highly folded regions, and is emphasized by the term "basin" applied to several of the Wyoming oil fields (Figs. 44 and 45).

Break-overs.—The term "break-over" is sometimes used to designate a crest, both structurally and topographically, and signifies that the dip is nearly in opposite directions on opposite sides of the point. In reconnaissance work in oil-field geology it is sometimes employed to denote a point topographically higher than the surrounding area which coincides either with the crest of a fold, or with some point on the axis of an anticline such that both the topographic surface and the rock beds appear to dip in opposite directions on opposite sides of the point. In other cases it is used simply to designate a point where the dip reverses. At times such a break-over is recognized by the presence of dip slopes in opposite directions on opposite sides of the elevated point, but more often by the symmetrical profile of the hill, or better by the absence of erosion escarpments and the

lack of the asymmetric outline usually caused by the regional dip.

This evidence is of value in reconnaissance work and not uncommonly in detailing, where it can be used to locate the probable position of the crest of a fold in cases where exposures are few and where they occur only around the periphery of a probable structure. It should be used for this purpose only in case exposures are insufficient to permit of the application of more exact methods.

Radiating Drainage.—Where ocean or lake sediments have been folded and later converted into dry land by elevation or by the retreat of the water, the surface will conform closely to the structure. The streams of the new drainage system will start at points which are topographically and structurally high and flow in the direction of the surface slope and rock dips (consequent streams). Points structurally high will be marked by ridges and hills from which the streams will radiate and the synclines by the points of convergence of the minor and the location of the major streams. This is particularly true where the area is still very young and but little structural adjustment of drainage has occurred (Fig. 46).

Where folding takes place in an area with a previously established drainage system part of the structures will, under favorable conditions, be marked by topographic elevations. In so far as this takes place, conditions are favorable for the formation of radiating drainage both because of the surface run off and the underground drainage.

While all topographic elevations may be considered as somewhat favorable for the establishment of radial drainage, it is to be noted that those that are also structural are by far the more favorable for the development of the more perfect radial arrangement. This is because on a structural and topographic high the rock beds slope away from the crest in all directions about equally and as a result all slopes drain off about the same quantity of water and erode with equal ease; while on a topographic high that is not also structurally high, the various slopes will usually

not be structurally similar, some being escarpment slopes, other dip slopes, and hence they will drain away unequal amounts of water and erode at notably different rates, forming a drainage that does not show radial symmetry.

This feature is best developed, and is of particular importance, in the still immaturely dissected mounds that mark the sites of the salt domes of the Gulf Coast Plain (Fig. 46). Well-marked cases of drainage radiating from a central point may, and sometimes do, occur where no dome is present, but the existence of such drainage is suggestive, and wherever seen, should be investigated.

Bends in Streams.—Consequent streams flowing across an upraised area with local topographic elevations and structural conditions tend to pass around such elevations and then to continue the general direction of their course. In so far as structural elevations are shown by the topography, the streams which encounter them will be locally diverted from their general course (Fig. 46).

Streams which antedate the period of folding may or may not be deflected from their course by a local uplift, depending upon the relative rate of elevation and the rate at which the streams are able to erode their beds. If the uplift is no faster than the stream is able to lower its bed, its course may be unaltered, in which case it is a true antecedent stream.

Those streams which antedate as well as those which are younger than the structural features are affected by the principle of monoclinal shifting. In areas of inclined resistant strata, the streams seek and tend to remain on the softer members, a condition which results in a slow shifting of their course down the dip.

This condition applies to streams of all sizes, but in the Mid-Continent Field the small streams are more indicative of structural conditions than are the larger ones. However, many of the bends of the Mississippi and Missouri rivers are probably traceable to structural causes, although many bends of streams are not due to structures at all. There is a reason for all deviations

from a straight course, and a thoughtful consideration of these reasons sometimes leads to the discovery of structural conditions.

Side on Which Tributary Streams Occur.—The presence of a ridge or a divide implies that the direction of drainage on its two sides be almost diametrically opposite to each other, but it does not imply that the amount of water derived from the opposite slopes and the number of tributary streams on these slopes shall be the same. The side on which the beds dip towards the valley tends to be longer and more gentle than the opposite side and not only catches more water as run off but also a great deal from seepages and springs. It follows that tributary streams are more abundant here (Fig. 42) and that the greater number of longer and larger tributaries enter a stream on that side on which the structural dip is towards it.

This principle applies best to cases in which the minor valleys are occupied by dip streams and the major by strike. It applies only indirectly to tributary strike streams which should be equally abundant on either side of the major stream. Its perfection of development and its value in determining structure vary between these two extremes. While this criterion is undoubtedly occasionally of use in the field, it is probably of more direct value in determining likely areas by the study of maps, on which the relations of the streams can be easily seen. In the field, where dip slopes and asymmetrical valley sections are well enough developed to control drainage in this way, they are themselves likely to be noted as such.

Rough Topography.—Rough topography is characteristic of regions in late youth or maturity, the land surface being comparatively high above sea level and the streams active. Land elevation, even on a large scale, is almost invariably accompanied by local folding or deformation of some kind. This, by creating topographic elevations and by influencing erosion because of local fracturing and increased dip, is exceptionally favorable for rapid differential erosion. Under such conditions the soft, less resistant beds tend to become valleys and the hard, resistant ones to stand out as hills and ridges. The greater the dip and

the difference in ease with which alternate strata are eroded the greater is this tendency. It is to be noted that this condition applies chiefly to areas where alternate hard and soft strata are being eroded. Where the angle of dip is high, as in parts of southeastern Oklahoma and Kentucky, the influence of hard layers is increased by that of the bedding and joint planes, but in the absence of resistant layers very rough topography is seldom formed, even where there has been considerable deformation.

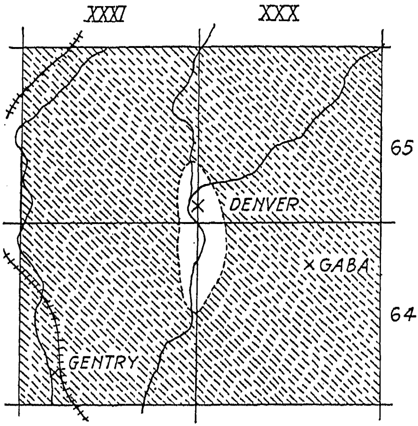


FIG. 47.—Inlier; Lansing surrounded by Douglas, Worth and Gentry Counties, Missouri. (*After Buehler.*)

The significance of rough topography is chiefly, however, that conditions favorable for the accumulation of oil and gas, if present, are more easily recognized, becuse extreme dissection favors the exposure of hard, resistant formations which are best adapted for structural observations.

Inliers and Outliers.—The truncation of a dome or anticline by denundation will expose an area of older beds (inlier) surrounded by younger ones (Figs. 45 and 47). A similar condition may be brought about by unconformity and also by faulting, in which case the inlier will be found on the upthrow side of the fault. Because of topographic relief all folds are not marked by

the presence of inliers, but the presence of such clearly determines the location of a point which is structurally high, such as may be caused by a fold, a fault, or an unconformity.

Where an area of younger rocks (outlier) is found surrounded by older rocks under such conditions as are not to be explained by their relative elevation or by unconformity, the presence of a syncline (Fig. 48), or a fault is definitely proven, the exposure being on the downthrow side in the latter case.

Inliers and outliers may yield much practical information in studying geologic maps, and sometimes are of assistance in the field where outcrops of quite unexpected formations, unlike

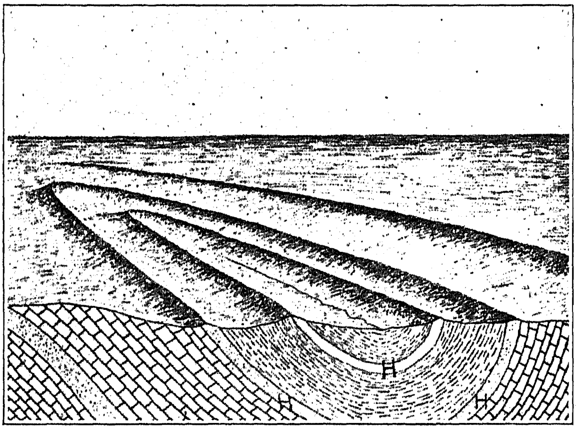


Fig. 48.—Outlier resulting from syncline. (*After Willis.*)

those of the general region, are exposed in isolated spots under conditions which can not be explained by the topographic features alone. Such is the case in the Gulf Coast Field where small outcrops of Cretaceous or early Eocene rocks are exposed in many cases at the crests of small domes, entirely surrounded by later Tertiary or Quaternary beds.

Soil.—To be of value in determining structure soil must usually be residual and must possess certain peculiarities of chemical or textural composition by which it may be recognized as having

resulted either from some certain layer or stratum or from a stratum of a certain lithologic character, such as limestone or sandstone. When characteristic it may identify the position of the parent formation.

While elevations at the upper limit of such soil occurrences are sometimes taken because of the want of exposures, soil is more often of service to the geologist in "walking the outcrop" along a hillside where exposures are not continuous, by aiding him to feel certain of his correlation.

It is also true that the nature of the soil determines in part the character of the vegetation. One often sees evidence that certain plants or trees favor limestone soils, others sandy soils, and still others soils from shale and slate.

Because of chemical alterations, leaching, and mixing with other substances such as humus from plant decay, soils may lose many of the characteristics of the parent rock.

The abnormal occurrence of salt, gypsum, sulphur, asphaltic residue, paraffin dirt, and "sour dirt" ("copperas dirt"), in the soils of many Gulf Coast salt domes is a factor commonly taken into consideration in a search for possible oil structures in that region.

The salt cores of the Gulf Coast domes are rarely actually exposed, but salt is often formed in the soil, and salt marshes commonly occur above the dome. Likewise the presence of abnormal amounts of salt or gypsum in the soil of this area suggests the possible proximity of a dome and calls for further investigation.

Small particles and seams or veinlets of sulphur in the soil often result from the oxidation of sulphuretted hydrogen in seeps or springs, and not uncommonly are associated with Coastal Plain salt domes. Owing to the very prevalent association of sulphur bearing gases, such as H_2S or SO_2, with the salt domes, the presence of sulphur in the soil in that region is usually considered an indication of the presence of favorable conditions for oil accumulation.

"Sour dirt" or "copperas dirt," dirt impregnated with sul-

phates resulting from the escape of SO_2 or H_2S or both, are also common and are thought to have about the same significance as sulphur in the soil.

Asphalt in the soil has usually been taken to be an indication of oil seepage, and hence to point to conditions favorable for accumulation. Since escaping oil can move long distances laterally, it must be borne in mind that not always, by any means, will the point of maximum accumulation be direclty beneath the seepage, so that the drilling of seepage areas has often lead to disappointing results. Nevertheless, it is an indication not to be overlooked. In the Coastal Plain, it is said that asphaltic sea-wax[1] has been known to have been thrown up by the waves; but this must not be confused with asphaltic soils related to true oil seepage.

"Paraffin dirt" has frequently been cited as an indication of oil. Formerly believed to be a true paraffin derived from oil seepage, this substance is now believed to contain little or no true paraffin, but to be a form of peat, or humus, limited to soils where gas seepage has prevented more perfect decay of the organic soil constituents.[2]

If it is true, as has been suggested, that methane (marsh gas) may result in the formation of so-called paraffin dirt in soils, then such occurrences could no longer be considered to point with certainty to oil accumulation and seepage. The entire subject is one of very recent interest and still open to various interpretations. The fact may be that while "paraffin dirt" is genetically connected with true natural gas seeps from salt domes in some cases, in others it may result from seepage of recently formed marsh gas and have no significance. Its discovery, however, should at once excite suspicion and lead to a very close scrutiny of the areas in question.

[1] Matteson, W. G., Principles and problems of oil prospecting in the Gulf Coast Country, *Bull.* A. I. M. E., No. 134, p. 444, 1918.

[2] Brokaw, A. D., An interpretation of the so-called paraffin dirt of the Gulf Coast Oil Fields, *Bull.* A. I. M. E., No. 136, April, 1918, p. 947. See also discussion of this paper in Nos. 139 and 140.

Float.—Attempts to follow the trace of a formation along the erosion surface are commonly met with difficulty because the outcrop is discontinuous. In fact, it is an ever increasing wonder to the geologist that all traces of the presence of a truncated limestone stratum can be so completely concealed. Where there is no similar bed sufficiently close that the float from the two can mix, or where the float from the bed followed is of such a character that it can be distinguished from otherwise similar beds, the covered line of truncation can often be followed from one outcrop to another by means of the fragments, and elevations can even be taken between at points where the highest float is found. The degree of certainty of such observations will of course depend upon conditions such as the abundance and distinctive character of the float, the topography, and the distance between exposures. In the Mid-Continent Field float is of great assistance in tracing the limestone strata of the Pennsylvanian series.

Water Seepages.—As the terms are here used seepages differ from springs in that the amount of water in the former is insufficient to flow over the surface, and in that the flow is less localized. Seepages are thus characterized by a linear extent rather than by one or two points of outlet.

Water falling as rain sinks through the upper pervious formations until an impervious layer is encountered, or until the water table or point of saturation of the rocks is reached. In the former case the impervious layer is generally a shale bed along the upper surface of which the water flows to where the bed comes to the surface on the hillside, where it has been truncated by erosion. Seepages of this type thus occur along lines of outcrop at the top of the impervious stratum, and are generally limited to that topographic slope on which the beds dip towards the valley.

Where a valley is located in a syncline or trough, seepage may occur on both hillsides and may be so interpreted. However, judgment should be exercised in all interpretations. During wet seasons or immediately after a rain the water table within

a hill may have been so raised that the water comes out on both sides of the hill irrespective of the direction of the dip of the rocks. Such conditions are here designated as *water table seepages* as opposed to *structural seepages*. Structural seepages are thus characterized by being apparent through longer periods of time than water table seepages, by their location being in the nature of a line, often well up on the hill-sides, as contrasted with the generally irregular points of issue of water table seepages, and by other evidence indicating continued moist conditions and the presence of an impervious stratum.

Yet under special conditions water table seepages may show any or all of these characteristics. Where the distance between drainage courses is large as compared with the surface relief, water may issue from the hillside through a long period of time, even though the beds dip into the hillside at that point. Usually water table seepages will take place unobserved under the soil and wash near the bottom of the valley, but where impervious strata and insufficient structural drainage occur, the back water so raises the water table under the hills that the water overflows the truncated edge of the impervious layer. This condition is uncommon and can generally be decided by means of one's knowledge of the area and by a consideration of the relation of the distance between drainage courses to the topographic relief.

The term seepage is sometimes applied to diminutive springs, or to springs during that portion of the year when the flow is small. The structural significance of seepages of this nature is identical with that of springs as described in the following topic.

Well-marked lines of seepage, well up on a valley side, are likely to mark the outcrop of a shale layer, and, where the line is moderately inclined, the direction and approximate angle of dip may often be suspected from a study of such a line particularly in conjunction with the vegetation developed thereon.

Salt seepages and sulphuretted water in the Coastal Plain region are said to suggest the proximity of a salt dome, and should be closely examined for corroborative evidence.

Springs.—Springs differ from seepages in the amount and localization of flow. Their origin and interpretation are much the same except that they infer, but do not necessitate, some other structural condition which has caused the localization of the flow. Not uncommonly this is due to a troughing of the beds, but it may be caused by the presence of a joint or fault, or by damming of seepage waters along all but a few points. Springs should always be carefully examined for evidence as to cause.

Those which occur high on the hillsides, on the slope opposed to the regional dip should be carefully inspected; and in the absence of evidence that they are water table springs, the suggestion is that they are the result of a reversal of dip, and the surrounding area should be examined for such structural conditions.

Vegetation.—Under the arid or semi-arid conditions which characterize many of the oil fields both moisture and soil are important factors in determining the amount and character of the vegetation and the portion of the year through which it will remain green. Water seepages and shale beds, commonly found together, are both favorable to plant life. It is therefore often possible to determine the direction and amount of dip by a change in the kind of vegetation or by its ranker and greener character, a condition which occurs as bands along certain hillsides, especially during certain seasons of the year. On such slopes detailed work can often be successfully carried out, even in the absence of a single rock exposure, while in reconnaissance work the general direction of the dip can often be determined at a distance of a number of miles. In fact in some cases such bands may be most readily seen at a distance.

Resistance to the penetration of roots, a deficiency of moisture, and excessively steep slopes are detrimental to tree growth. Since these conditions are often dependent upon the structural position of the strata, the relative abundance of tree growth on

the various hill slopes may largely be determined by, and be indicative of, the structural condition.

Where the surface formation is soft, as clay or slightly cemented sandstone, and the slopes are therefore characteristically at low angles, no relation between the abundance of tree growth and the structure is to be expected, since the roots can penetrate through the beds almost as readily as along them, and the penetration is so deep that it minimizes the difference in the relative amount of moisture usually noted on dip and escarpment slopes. But where the beds consist alternately of hard and soft layers, especially of limestone and shale, the difference is often pronounced.

The hard layers which characteristically underlie dip slopes resist penetration by the roots, causing them to be poorly attached and often of such shallow penetration as not to reach permanent moisture. Surfaces which truncate the beds permit of easy penetration by the roots in directions parallel to their bedding, a condition which, for a given angle of slope, is best developed where the slope is in the direction opposite to that of the dip of the beds.

The underground drainage is usually in the direction of the dip of the beds so that the maximum amount of moisture is supplied on those slopes which dip in the direction of rock inclination but at a greater angle. The minimum moisture is found on the opposite slope.

Unfavorable extremes may in each case be found either on those slopes which dip in the same direction as the beds, or on those which dip in the opposite direction. Dip slopes are characterized by poor penetration and low moisture while areas which slope in the same direction as the beds dip, but at a steeper angle, so that they truncate the beds, have the best of conditions, fair penetration and abundant moisture. Escarpment slopes, on the other hand, have good penetration, but a low moisture content, and may in some cases be so steep as to allow of no soil accumulation and but little tree growth.

Both the absolute and the relative effects of these factors

vary with local conditions, each being of major importance in certain places. The effect is best shown in semi-arid regions where the difference in the ease of penetration, the amount of moisture, or the steepness of the slope may be the deciding factor in determining whether or not there can be tree growth.

Oil and Gas Seepages.—Seepages of oil and gas are among the earliest and most widely recognized indications of possible oil fields. That they are valuable indications is generally admitted. Sometimes films of iron oxide over pools of water have been mistaken for coatings of oil, the superficial resemblance being marked. Such coatings break into angular fragments when disturbed and will not form in lines as will oil. Odor and inflammability should constitute further and sufficient tests for discrimination. Gas seeps may consist of carbon dioxide (CO_2) (non-inflammable) or of marsh gas, and bear no relation whatever to petroleum occurrence. Many serious errors have been made in assuming that a small escape of marsh gas indicated the presence of a large body of gas or of petroleum. Such gas is being constantly formed in most sloughs and bubbles to the surface on being disturbed.

Nor must it be forgotten that, even though seeps are marked, accumulation may never have been in sufficient quantities to yield paying amounts, or that the seep may have been so large and existed so long as to totally deplete the reservoir.

It must be remembered also that oil (and this is even more true for gas) may move laterally considerable distances before escaping to the surface, consequently the pool is not often directly below the seep, so that when a seep is located, a careful structural examination should be made, as it is usually not advisable to drill directly on the seep or even close to it. The seep is merely an indication that a given horizon is oil or gas bearing, and that where favorable structural conditions can be located it may be worth prospecting.

Faults and Their Recognition.—A fault may be defined as a fracture or a break in the rocks, along which there has been relative movement of the walls (Figs. 7–13). The discrepancy

between the ends of the beds will depend on the amount of displacement along the fault plane, which may vary from a few inches up to several thousand feet.

It is not often that one can actually see the fault plane in the field. Perhaps the most commonly used indication of faulting is based on the distribution of the formations. Not uncommonly when "walking an outcrop," one comes to a point where the bed seems to end abruptly. If the bed is one that outcrops conspicuously and the disappearance seems complete, one would be led to suspect a fault, especially if the topographic conditions remain favorable for an outcrop. Faulting must not be assumed on such evidence alone, however, as beds are sometimes so completely buried as to defy location, not even float or soil giving any clue.

If a fault is suspected, corroborative evidence should be sought. This may consist of tracing the bed on the opposite side of the adjacent valley, or hill. If it is found to disappear abruptly there also, one's conclusion of faulting is greatly strengthened.

Further, if the position of the lost bed is found to be occupied by rocks of an entirely different character farther along the hillside, in such position that the normal dip of the beds cannot account for their location, the evidence of faulting is very strong, and, in absence of opposing evidence, should be accepted.

Slabs of rock standing in a vertical or a steeply inclined position in the soil near the point where the bed seems to be cut off, especially if such slabs are striated or sickensided and are arranged along a line, constitute additional confirmatory evidence, although slump or even a very minor buckling of the rocks may cause slabs to stand in a steeply inclined manner.

Where beds are flat lying, or nearly so, any very sudden departure from that position to steep inclination, while it may represent folding or slumping, should also be investigated for evidence of faulting.

In cases where a series of rather similar limestone beds occur in sandstone or shale, it may happen that the ends of two dis-

tinct and separate beds are so faulted as to be brought into line and made to appear like a continuous bed. Notable cases of this have been reported, in which the observer walked what appeared to be a continuous outcrop, whereas in reality he walked from one limestone across a fault onto a similar limestone that should normally have been many feet above or below.

Faulting must be carefully identified in the field chiefly because failure to recognize it commonly leads to incorrect correlations and hence to incorrect mapping of structural conditions. Faults must be located not only that the true structural conditions may be known, but also because they may either condemn a fold by their presence or furnish the necessary conditions for the accumulation of oil and gas.

Where to look for Outcrops.—Little can be accomplished in the way of structural mapping in areas where no outcrops occur. In certain regions in which bed rock is deeply buried by alluvium, glacial drift, or dune sand, the geologist can accomplish but little in the location of favorable structural features. In regions where outcrops are few, much time can often be saved by knowing where to search for rock ledges. As a rule, very flat hill tops and broad meandering stream valleys are not likely to show exposures of bed rock. Steep hill slopes are more apt to be favorable than gentle ones, and the steeper upper courses of valleys than their broader lower reaches. The more ruggedly a region is dissected, the more apt there are to be bare ledges exposed.

Outcrops of the Oil Sand.—In wild cat territory, especially if the distance from production is very great, outcrops of prospective oil horizons furnish valuable information. Where exposed by erosion most, if not all, of the available gas and oil in the immediate area will have escaped, as in the San Juan region of Utah. The farther the outcrop from the proposed test, and the greater the intervening folding, the less danger of such drainage.

The presence of petroleum residues in sands has the same significance as oil seeps, showing that the conditions have been favorable for the generation of oil and increasing the probabilities

of there being undrained deposits if the conditions are otherwise favorable.

"Red beds" are in general unfavorable to the generation of oil and gas within themselves because they are unusually almost or quite barren of organic remains. However, oil and gas generated elsewhere may migrate into such strata and have been found in formations of this character. Coarse, porous sandstones interbedded with black shales or porous dolomitic limestones are usually favorable because they contain organic matter from which the oil and gas may be derived, and also include members well adapted to the migration and accumulation of these substances.

Beds may change in character within short distances, and their irregularity along the outcrop often furnishes the best available evidence as to what variations can be expected in the other directions.

CHAPTER IV

FIELD OPERATIONS

THE FIELD PARTY

Transportation.—The oil geologist is required to go into all sorts of out of the way places and to do his work in a minimum amount of time. It therefore follows that much of his traveling is done on unimproved roads and that he must adopt the most advantageous method of transportation. Traveling on foot, on horseback, by buggy, by motorcycle, and by automobile have each been found to be applicable to certain conditions. While in some places, as in parts of Kentucky, it is necessary to travel on horseback or on foot, there are very few places in the western states that cannot be approached sufficiently close by an automobile, and this is now the universal and almost exclusive method of travel.

Reconnaissance work can usually be carried on very well from an automobile and a larger area can be covered in this way than by any other means, although such work must often be supplemented by various side trips on foot. In fairly level country and even in areas which are quite rough, the instrument man in detailing often keeps the car near him at each set-up, while in many cases the rodman has used either a car or a saddle horse with very satisfactory and very much accelerated results. The work that can be obtained from a cheap light car and the difficult road conditions which can be overcome are remarkable, and while the life of a car under very bad conditions may be limited to one or two years, the time saved more than compensates for the additional expense.

The motorcycle has been used in reconnaissance work with fairly satisfactory results even in rough and sandy areas. How-

ever, it requires much more skill for safe operation than a car so that the chance of being injured is greater, and it is not adapted to the carrying of an assistant or baggage, neither is it the most comfortable means of transportation in dust, sand, ruts, or mud; conditions which insure that its use will be opposed by employees and that it will not even be given a fair test in most cases.

Personnel.—Individual field parties consist of one, two, or three men. In reconnaissance work each party consists of a geologist with or without a driver, although the use of a driver is preferable so that the geologist may give all of his attention to the area he is covering. In places like portions of Kansas, Oklahoma, and Texas where the dips are low, the exposures few, or the vegetation so plentiful that the general structure is difficult to read, it is quite satisfactory to use an instrument man as a driver so that one is in a position at any time to take the elevations of a few points and thus quickly determine whether or not the area is worthy of further attention.

In detailing, the party usually consists of a geologist and an instrument man, but under some conditions it has been found to be expeditious to employ an extra rodman to assist the geologist. In open country where there are few trees, and where many and long sights can be taken from one set-up, the instrument man can take care of two rodmen (the geologist and an assistant), but in timbered or rough areas where set-ups are numerous, a third man is of but little value. In general these conditions so change from day to day and the problems of correlation are so difficult that the employment of a third man is not practicable.

The use of the automobile has made it possible to work so far from one base that only in very rare cases is it found necessary to consider the use of a camp outfit and its attendants.

The Geologist.—The general requirements of a geologist have been well summarized by Hayes in his "Handbook for field geologists" from which part of the following is taken.

Physical and Mental Qualities.—"To insure even a moderate degree of success as a field geologist one must possess certain physical and mental

qualities, the lack of which may be in no wise to one's discredit and may involve no particular disability in many other professions. It is well therefore to determine in advance of the long apprenticeship required whether or not the candidate possesses these necessary prerequisites.

"It is not the desire to discourage young men from entering this profession. A healthy body will respond and develop to meet the demand and, to one who likes outdoor life, the work will doubtless be more pleasing than most other subjects.

"The first qualification is a good physique and a strong constitution, for sooner or later severe and long-continued physical exertion will be required and a defect in ability to sustain this exertion will be a serious handicap.

"The second is adaptability. Few occupations present so wide a diversity in conditions under which work must be carried on as that of the field geologist. His surroundings may vary all the way from the luxury of a summer hotel to the bare necessities which he must carry on his back, and he must be able to adapt himself with equal readiness to either extreme. If one cannot so adapt himself, but is dependent upon any particular kind of surroundings, he should abandon the idea of becoming a field geologist, for he will find the occupation extremely unsatisfactory.

"A geologist must possess a practical knowledge of horsemanship, of boating, and of general woodcraft, so that he will be equally at home in the saddle, in the canoe, or on foot in a trackless forest. One is fortunate who has already acquired this practical knowledge, but if he does not possess it he must be sure that he has an aptitude for acquiring it quickly."

The requirement of a good physique is more important in petroleum geology than in many other branches of the subject. As the work is carried on from day to day through summer and winter the petroleum geologist not only encounters high and low temperatures together with great and abrupt changes, but also poor living conditions and bad water. The use of the automobile has improved the conditions much, but geologic work is still carried on in many undeveloped areas.

Training.—No one can fully understand the principles of geology who has not had a good grounding in the fundamental sciences. That one may become a proficient geologist without

recourse to the assistance of an instructor is only theoretically possible, although a general knowledge of the subject can be so obtained.

The field training of a geologist, *i.e.*, putting into practice what he has learned at school and the observation of new facts, especially the latter, is of equal importance with the preliminary training and, perhaps, more likely to be only partially successful because the student who has been guided and pushed through school is now for the first time left to his own resources.

Preferably he should start his field work in the capacity of an instrument man. A thorough knowledge of the manipulation, accuracy, and limitations of the instruments will later be of value in supervising and training instrument men, and in the coordination of this work with that of the geologist. But more important than this is the opportunity to see and learn the practical application of geologic methods.

Our colleges and universities are turning out young men with good preliminary training who commonly enter upon their new work with enthusiasm, yet many of them are inclined to forget that life is a continuous school and that their training is not ended when they are able to follow an outcrop with a fair degree of certainty. A constant study of the interrelation of topography, drainage, stratigraphy, and structure is needed. There is a reason for the location and shape of every hill and valley, and this reason almost always contains information that is of value in determining geologic structure.

Geologists who can do fair detailed work, and who can correctly interpret general structural criteria which have been called to their attention are numerous, and some of them become very expert in the mechanical following and identification of outcrops. But men who can see and understand what they look at, men whose eyes call to their consciousness any condition abnormal to the regional dip features, are scarce. They are the more valuable for both reconnaissance and detailed work. When outcrops are uncertain one will map a structure as he sees it, so that it is essential that he "see it" correctly. A young

geologist who, in driving through an area in which he is to work, chats with the driver, and keeps his eyes and mind from the consideration of the structural features which he is passing, is not developing to the efficient state which might be his. Responsibility, with its accompanying "grief," is a great factor in impressing indelibly on a man's mind associated criteria, so that when his eyes again see the same features, they are immediately called to his consciousness.

Responsibility goes with the rod since the geologist or rodman is usually in charge of the party. Few positions require men of greater integrity. Not uncommonly the geologist is in possession of information valuable to others besides his employer or client. Not uncommonly he can profit, at least temporarily, by lending his name and influence to projects that he knows are not fair to all concerned. True honesty also includes careful and conscientious work in the field for a needless error may result in the loss of valuable opportunities or of thousands of dollars spent in unwarranted drill tests.

Suggestions to Geologists.—(1) Probably the most important suggestion that can be offered a young geologist is to *walk all outcrops.* There are limestone "zones" which consist of alternate limestone and shale strata, in which the layers may be very irregular in thickness and interval. They may thicken and thin, come in and die out, in short distances. It is seldom that one can walk over a hill and safely identify a given stratum on the other side.

(2) In general, carry two or more outcrop lines if possible so that by the outcrop of one or the other, and by the interval between them you may know that your correlation is correct. A given stratum seldom outcrops continuously and occasionally a fault will bring together two similiar strata, a proper identification of which may be missed without the use of a second stratum and the interval.

(3) Help the instrument man.

(*a*) Give him only such sights as he may reasonably be expected to get with the required accuracy.

(*b*) Make it a point to stand with your feet at the same elevation as the bottom of the rod, for the instrument man often identifies the rod readings by points on the rodman's person.

(*c*) Hold the rod so as to obtain the best practical illumination (note the increased legibility of fifth rod from the left side in Pl. VII). If it is questionable as to whether it is better to give more illumination or a better view of the rod, rotate it slowly about its vertical axis through possibly desirable angles. The instrument man will take the readings at the best point.

(*d*) In giving a sight, expose a maximum portion of the rod as viewed through the instrument. Quite commonly the lower foot or two cannot be seen from the point of set-up, while in the brush care is needed to expose a sufficient length of the rod for a stadia reading. The longer the sight the more important it is that a maximum portion of the rod be visible, but care should be taken not to confuse the instrument man by holding it on a point higher than that on which you stand.

(*e*) Where timber intervenes and there is a chance that a limb, either near you or near the instrument, may interfere with the sight, after waiting a minute move the top of the rod slowly back and forth in a vertical plane normal to the line of sight. This may permit of the reading of a point otherwise obscured.

(*f*) In giving a sight it is well to get into the habit of holding one or both hands and forearms in a horizontal position as a marker of some definite point, such as the five-foot division on the rod.

(*g*) It may happen that because of obstructed view the instrument man may not be able to see a sufficient length of the rod to make determinations. In such cases the rodman may, providing the conditions are such that there is no probability of the instrument man using points on his person for determining the rod reading, lift the rod from the ground and hold it as high as he is able. This should be done on side-sights only and the instrument man must be informed, at the first opportunity, of the distance the rod was lifted above the point.

(*h*) In many instances where the instrument man cannot see the rod when placed on the desired station, the determinations

can be made if the rodman will pace the distance and determine by hand level the elevation of a nearby point, preferably in the line of sight, where the rod can be read. The corrections are given to the instrument man at the first opportunity.

(*i*) *Signals.*—The signals by means of which the geologist (the rodman) and the instrument man communicate with each other at a distance should be as few, simple, and legible as is practicable. In reading such signals the greater difficulty is experienced by the rodman, as he usually relies upon the unaided eye, while the instrument man has the advantage of his telescope. A few rodmen carry a small field glass, to aid them in distinguishing signals.

It is expedient to be able to give signals by three different methods, each being the most advantageous under certain conditions. These methods are by arm or body movements, by whistle, and by mirror flashes. Arm movements are the most used, whistle and mirror signals are of particular value in attracting attention, and mirror signals can be read at distances such that the others can not be seen or heard. The flash from a mirror on a sunny day is so brilliant that it will usually attract attention immediately.

The information most commonly conveyed by signals is in part as follows: station; "rod-up;" "release;" turning-point; "search" or "where-are-you" call; move to right; move to left; move forward; move backward; and section corner or land mark.

The call by the rodman for a station and the "rod-up" reply by the instrument man, should be the same since there is no chance for confusion, and since the repetition of a signal is the recognized means of acknowledging it. This may be given by waving the extended arm above the head, but the rodman commonly designates a station, or point where observations are to be taken, by holding the extended rod in an inclined position, or by moving the upper end of the extended rod back and forth, sometimes supplementing this by waving his arm over his head until he is recognized by the "rod-up" signal. A single blast from the

whistle or repeated flashes from a mirror may also be used for this purpose.

When the instrument man has finished his observations he "releases" the rodman by raising and lowering both arms extended to the sides. Two blasts from the whistle is often a convenient "release." The mirror is used for this purpose only when other means fail, because parts of the instrument reflect the light giving similar flashes which may be misunderstood. The rodman accepts a mirror "release" reluctantly and only when he is convinced by the rapidity and number of the flashes that they are intentional.

The turning-point signal may be given by a full arm circular movement in front of the body, by six short blasts of the whistle, or, if necessary by mirror flashes. Inasmuch as an error in the observations taken upon a turning-point enters into all of the following determinations, the station is not located at a great distance from the instrument, usually less than half a mile, and the observations are taken with more care than are those of side stations. Special conditions such as longer shots, poor background, or the presence of brush may cause the rodman to have trouble in seeing that his turning-point signal has been accepted. However, if the same order of procedure is always followed there is little cause for a misunderstanding of signals. The rodman signals a station which is accepted by the "rod-up" signal from the instrument man. The former then signals a turning-point and refuses to put up his rod until it also is accepted in kind. The instrument man looking through the instrument notes that the rod is not up and has no difficulty in recognizing the turning-point signal. He then replies by arm movement or by the whistle. If the rodman fails to recognize these, as shown by his failure to "rod-up," the former may resort to mirror flashes. The station having been recognized by the instrument man, the rodman after giving the turn signal for such a time that he is sure that the instrument man must have seen it, and recognizing that the conditions are such that the regular signals probably cannot be seen by him, will recognize a signal of almost any kind as an acceptance.

While it is supposed to be part of the duty of the instrument man to keep track of the whereabouts of the rodman, this is often impossible. The latter in following an outcrop around a hill or through the brush or in going off on a side trip to check the correlation, often disappears for short or long intervals, not uncommonly to appear again unexpectedly at some other point. Also the rodman in giving all of his attention to the immediate problems may lose track of the instrument man and spend time and patience in vainly signaling an unresponsive rock or stump on a distant hill. A "search" or "where-are-you" call such as three blasts from a whistle or the flashing of a mirror over the area where the one sought may be, will often overcome this difficulty.

It is quite essential that land monuments such as section corners be located both in order to determine the relation between the geologic structure and the land lines and as a check on the direction and length of the traverse being run. The instrument man may signal the rodman of the presence of a corner, which his map shows to be in close proximity, by moving the extended arms alternately from the horizontal to the vertical position or by four blasts from the whistle, the first two being separated by a pause from the second two. However, it is better if possible to anticipate this and other conditions which may necessitate signals, and talk them over when the two members of the party are together. This together with a careful location of all stations will eliminate the need of complicated signals. The main difficulty in signaling is found in the rodman trying to attract the attention and in reading the signals of the instrument man. In short sights but little difficulty is experienced, but where the distance is greater than 2,000 ft., care and often ingenuity must be exercised. Under such conditions signals should be movements, not positions, and these should be assisted by holding in the hand, or hands, a white article, such as a handkerchief or the face of an open note book, or a black article, such as a hat or the back of a note book, that color being chosen which contrasts the most with the background. Arm signals often cannot be distinguished

apart at distances of half a mile or greater, and it is rarely essential that they should be. The rodman accepts the first signal as the "rod-up," and the second as the "release," providing a sufficient interval of time has elapsed between them to allow for the taking of the instrument readings. Therefore if it becomes necessary to give a movement signal it should precede the "rod-up" or follow it so closely that there can be no danger of its being taken for the "release," and should be continued until the rodman surmises its meaning. A moving object is quite readily detected by the eye, and under very bad conditions an instrument man may be compelled to run out to one side of the instrument and then quickly to the other in order to indicate to the rodman that he is signaling.

The Instrument Man. *Qualities and Training.*—The physical requirements of the instrument man differ in no way from those of the geologist or rodman. Preferably and not un ommonly the instrument man is an aspirant for the position of geologist. In such cases their preliminary training should have been the same.

That the instrument man should understand the principles of surveying is evident; he should also be resourceful. The ever varying conditions under which he works, such as the length of sights, varying illumination, partially obscured vision, windy weather, varying backgrounds, difficulties of signaling, and different instruments with different attachments, necessitate that he know all the methods by which such difficulties can be overcome, be familiar with their general accuracy, and be able to choose quickly and unhesitatingly between them.

A young instrument man in an earnest effort to "make good" is sometimes tempted to commit the one unpardonable sin of falsifying his errors of closure. Missed sights can be retaken, wrong computations may be recast, but a single wrong elevation may result in the loss of thousands of dollars and perhaps of the rodman's reputation.

He should have a general knowledge of structural geology, and in particular of the general features of the work of the rod-

man. To a considerable extent the rapidity with which the work is carried on depends upon the location of instrument stations which must to a large extent be left to the judgment of the instrument man.

One might succinctly express the general idea of an instrument man's duties by stating that he is supposed to get whatever sights are given him, always to have his computations and records completed, never to lose sight of the rodman, and never to complain of the length of sights and turning-points. Of course this is impossible but it expresses the general goal towards which he should strive.

Suggestions to Instrument Men.— (*a*) The first requirement is accuracy, but only to the extent that it is needed for the work in hand. Greater accuracy and neatness are desirable and should be striven for, but they must be subordinated to rapidity in taking sights. The time required to complete a sight between the "rod-up" and the "rod-down" or "release" signals varies with conditions but is usually from 20 to 60 seconds. The rodman does not appreciate being delayed or repeating a sight.

(*b*) The instrument man is entirely dependent upon his alidade. It follows that he should know it thoroughly. The line of collimation and the spacing of the stadia wires should be tested occasionally although they seldom give any trouble.

The striding level needs more or less constant attention and should be tested at least a number of times a day and sometimes at every set-up; experience with a given instrument determines how often this should be done.

It may be safely assumed that the graduations of the vertical arc are correct.

The divisions of the Beaman stadia arc, if present, should be tested against those of the vertical arc. Instruments of the same make and model do not have the same accuracy.

The gradienter screw, if present, should also be tested against the vertical arc for accuracy. In old instruments special care should be taken to reduce the effect of "back-lash." (See pp. 96 and 203.)

The instrument man should know (preferably in tenths of a foot per thousand feet) the value of one division of the striding level bubble-tube, since this determines how carefully he must adjust and level the tube.

(*c*) Set up the instrument so as to be able to see as much as possible of the outcrop which the geologist is following.

(*d*) Other things being equal, save a sight by setting up on the outcrop.

(*e*) It is convenient to know the height of the different parts of the rodman's person.

(*f*) Where there is a choice, choose a background that permits the signals to be best seen. In general the sky line is the best background.

(*g*) Many errors can be prevented by becoming proficient in estimating distance; this is best done by estimating each sight before taking it.

(*h*) A competent instrument man should keep his elevations computed up to date at all times, without delaying his rodman, except on very short sights where there is but little time at his disposal. Likewise all computations must be checked. In most cases this can be done in the field.

(*i*) It is good practice to record all observations as taken, *i.e.*, if a half-stadia intercept is taken, or if the upper stadia wire is read in place of the horizontal wire, record it as such.

(*j*) Be sure of the observations. This may require that beginners take two readings of all observations and record them before "releasing" the rodman, but experienced instrument men can usually take all the observations and "release" the rodman before recording any of them.

RECONNAISSANCE WORK

Necessity for Reconnaissance Work.—In general, reconnaissance work consists of a preliminary examination of an area to determine what part of it, if any, warrants the time and expense of a careful detailed survey. Such a reconnaissance

should precede all detailed work, and will save much time by eliminating such areas as are clearly unpromising. The detailing of large regions without preliminary reconnaissance is a practice generally to be condemned, although it is often done because the chief geologist fears to leave to less competent subordinates the decision of what to map and what to omit. The accuracy of such work varies greatly with the plan of operation, with the difficulties encountered, and with the object of the survey.

Reconnaissance methods are also employed when large areas must be examined rapidly, especially if detailed information is not desired, or if time does not permit of more thorough work. Sometimes the definite presence of a structure and its approximate extent and size are determined, while in other cases suggestive evidence only, but not proof, of the presence of a structure is obtained. Not uncommonly it is highly desirable to determine, if possible, the location, approximate extent, and size of the structure so that the land may be leased before detailed work is undertaken, as the latter tends to attract attention to the area and not uncommonly results in an increase in the price that must be paid for the leases and even in the loss of some of them.

In many cases reconnaissance work will show that no favorable structural conditions are present, or that there are not sufficient outcrops to warrant an effort to make a detailed map. If the conditions are very well-defined, the reconnaissance may secure all the needed information. As a rule, however, reconnaissance, if the results are favorable, should be followed by detailed work.

Characteristics of a Good Reconnaissance Man.—Good reconnaissance men are scarce. They must not only know how to interpret conditions which are brought to their attention, a matter in which most geologists are quite proficient, but they must be able to *recognize significant conditions on sight.* Many men in driving through an area will permit their eyes to wander over conspicuously high or low regional dips without having them impressed upon their consciousness, or will see west-facing erosion escarpments in regions of west regional dip without being impressed by their significance. So common is this, even among

men of good education and training, that one is inclined to think that a reconnaissance man is born with certain peculiarities which the average man does not possess. Certain it is that a man will never be good at such work who does not make a careful and thoughtful observation of the topographic forms he meets from day to day so that he will not only know the meaning of deviations from the general type of the area, but his eye will immediately notify his consciousness of such changes.

Methods of Reconnaissance.—Where the area to be covered is large, such as the reconnaissance of any considerable part of a state, it is advisable to get all the available topographic maps of the area, and study them carefully before going to the field. Drainage peculiarities, asymmetric ridges or cuestas with typical dip slopes, and other features that can be recognized on the map, may suggest certain areas as being especially worthy of investigation. All available geologic maps should be examined carefully for faults, folds, and regional dips, and reports should be studied, to familiarize the observer with both the structure and the stratigraphy. There is no use wasting time in the field securing data that someone else has already secured and published.

Upon going to the field, one of the first matters to be considered is location. The field man should be supplied with a good base map of the area, if one is available, and on it he should constantly keep track of his location. If no map is to be had, he should learn the location of as many land corners and lines as possible, that he may always know where he is. In country that is sectionized, especially where roads follow the land lines, this is easy. In some part of Kentucky, West Virginia, Louisiana, and Texas, the matter of location is a difficult one. If it is not possible to determine absolute location, the field man should at least keep careful track of the relative locations of his observations, a matter very essential in the proper interpretation of structure.

After arriving in the field and ascertaining his position, the geologist makes observations regarding dip. (Criteria for the recognition of structure are summed up in the preceding chapter.) Where timber is abundant, observations may be wholly limited

to short distances. There are, however, many criteria for the determination of direction of dip that can be read to advantage only at a distance, and are often quite valueless at close range. Such are erosion escarpments, dip slopes, lines of outcrop with very low dip, lines of vegetation, and the like. When making observations of this character, an automobile equipped with a speedometer is of much assistance, as it enables one to view in a short time the same feature from several different directions, and to keep approximate track of distances.

Where the angle of dip is sufficiently pronounced so that the observer feels no doubt of its direction, it is at once indicated in its proper place on his map, by an arrow (Fig. 40). If there is any doubt, it is checked by aneroid, by hand level, or in some cases by telescopic hand level or alidade. Where there is any reasonable doubt as to correlation of beds sighted on, the outcrop should actually be traced between the points of observation. Nearby observations that are confusing by reason of minor variations are often easily checked at a greater distance.

In many areas of prominent outcrops, a very cursory examination will often reveal the fact that there is nothing but normal regional dip, and show that further work is not warranted. Or the preliminary examination may soon show that there are no outcrops whatever on which to make observations, and reveal the uselessness of further examination. If the presence of a "reversal" is suspected, elevations are usually checked by hand level, aneroid, or other means, and the observations plotted on the sketch map.

Reconnaissance should also include a study of the outcrops of possible oil sands and impervious cover, if they outcrop in the vicinity; and should include observations on water supply, fuel, and transportation, in areas that are structurally promising.

If the conclusion is reached that a detailed survey is advisable, the approximate location of the structure and the probable area to be mapped should be indicated on the sketch, particularly if the detailed survey is to be made by someone other than the man who made the reconnaissance. In such a case the recon-

naissance data should always be at the disposal of the man doing the detailing.

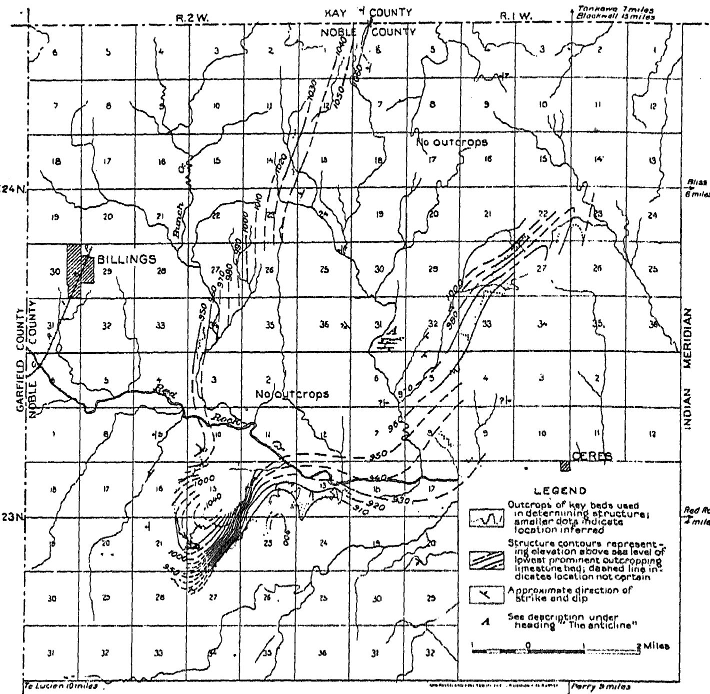
Semi-detailed work of rapid character can be carried on with the use of the following instruments: a compass; a rod; a telescopic hand level equipped with stadia wires; and an Abney level or one of the various types of pocket transit provided with a scale to read per cent. slopes. Distances, directions, and elevations can thus be determined with sufficient accuracy to allow of making a roughly sketched contour map. The work required is such as to occupy more time than is needed for general reconnaissance, and demands that the geologist have an assistant; but it is much more rapid than typical detailed mapping; and, where haste is essential, may sometimes be employed with advantage.

DETAILED SURVEY

General Description.—There is no sharp line of demarcation between reconnaissance and detailed work. As the names imply the former has to do with a preliminary, rapid, incomplete examination while the latter is concerned with the careful working out and mapping of the structural conditions in such detail as is essential to the valuation and exploitation of the area, in so far as this is permitted by the evidence. Where the structural conditions are very apparent, a little additional care given to the preliminary examination may be sufficient for the work at hand. Also, at places where there is insufficient data to permit of careful detailing, the two types of examination may be identical as the reconnaissance work may secure all the information available, and thus satisfy, so far as is possible, the requirements of the finished work. All the methods of detailing may be used in reconnaissance work to some extent. Thus, where exposures are poor or dips low, it may be desirable to take the elevations of two or three or more points on an outcrop to determine which way it is dipping.

In certain instances, the finished map is a combination of a detailed structural contour map in those areas in which detailed

information is available, and a reconnaissance map, with dips indicated by arrows, in those areas in which outcrops are not sufficiently continuous to allow of structural contour mapping (Fig. 49).



MAP OF ANTICLINAL FOLD NEAR BILLINGS, OKLAHOMA

FIG. 49.—Map of anticlinal fold near Billings, Oklahoma, showing combination of detail and reconnaissance mapping. (*After U. S. Geol. Survey.*)

Detailed work has been carried on in a variety of ways and, as is to be expected, the profession is not entirely in accord as to the relative value of these methods. One is naturally influenced by the methods he has tried and knows best, and the value of each method depends upon the conditions under which the work is to be done and to some extent upon the temperament of the

observer. For convenience of discussion detailing may be divided under two heads; location and elevation.

Location (including direction and distance).—Points may be roughly located by reference to local land marks, by their topographic position if a contour map of the area is available, or by a traverse in which the directions are taken by the use of a pocket compass and the distances by pacing. Such methods may be of value in heavily timbered area and when the work is being plotted on a very small scale. Locations may also be made in open areas by triangulation, that is, by taking the compass bearings from two known points and plotting the lines on the map. Such methods are crude, but there are times when one is compelled to make the best of unfavorable circumstances, and when such methods may be sufficiently accurate, especially as an aid in reconnaissance work.

When mapping is done by the use of a plane table, the direction of a point is taken by sighting on it with an alidade, either open sight or telescopic, and the distance measured by pacing or stadia. The bearing of the line is plotted directly on the map, and the distance scaled off according to the scale determined upon at the beginning of the work. This gives the location of the point. Sighting with an open sight alidade and measuring the distance by pacing are both sufficiently accurate when done by a trained man, but the method is slow and necessitates the securing of elevations by the use of a barometer or a clinometer. It is, however, about the best one-man method of detailing. The method of using the telescopic alidade has been described rather fully in a previous chapter.

In detailed work it is desirable to start at some known point, such as a section corner, and to "tie in" to known points at frequent intervals. There may be occasional instances where it is desirable to start at random and "tie in" on some known point later, but this is not often advisable.

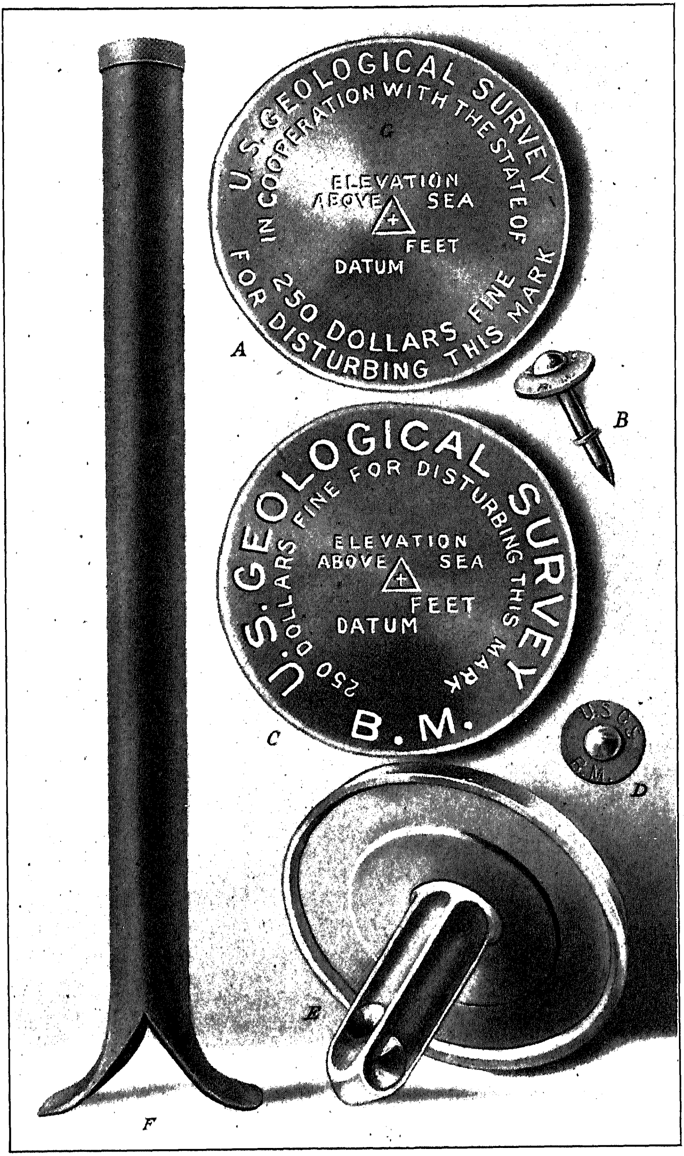
Elevation. *Bench Marks.*—A bench mark is any point the elevation of which has been determined and which is intended to be used in determining the actual or relative elevations of other

points. They are so indicated and described as to be readily found by the person or persons concerned through the time in which they are to be used. Those established for the use of the public are commonly marked by an inscribed bronze or aluminum tablet (Pl. XI), while those established by a surveyor for his own use during the mapping of a small area often consist of a small pile of rocks. Bench marks thus differ from stations in that the latter term is applied to all points the location or elevation of which is established or assumed and therefore usually with no intent on the part of the locator to visit them again. They are therefore less carefully determined and marked. Any station may become a bench mark providing it can be again located.

The United States Geological Survey, and Coast and Geodetic Survey, together with various State surveys have established bench marks at irregular intervals over most of the United States. Practically all of these refer to mean sea level, *i.e.*, the average height of the water, all stages of the tide being considered. Reference to these possesses the advantage that it gives the actual elevation, and, since they all refer to the same datum plane, one may at times check in on another bench mark and avoid returning to the starting point in order to check his run. It also has the additional value of assisting one in comparing conditions in neighboring areas without the necessity of running a traverse between them.

In many cases, such as the mapping of individual structures, the reference of elevations to sea level is no more advantageous than the determination of relative elevations from a bench mark of assumed elevation. One is then not justified in taking much additional time to establish sea level elevations. Therefore in detailing small isolated areas, especially if far from a bench mark, an assumed elevation for the starting point is used. However, one should carefully locate and describe all bench marks of assumed elevation so that it will be possible either to use them again or to establish their relation to sea level at any later date if it is found desirable to do so.

In mapping large areas the field work may or may not be



Geological survey bench marks. (*After U. S. Geol. Survey.*)

controlled by previously established bench marks, but in most cases such bench marks are established at convenient points at such distances apart as may be determined by the accuracy attempted. If they are to be used with a telescopic alidade survey, they should be established by a surveying level or an alidade. If to be used for barometric work, they may be established as above or by an aneroid. Where these bench marks are established by other than the one who is to use them, care must be taken to place them at points easily described and found. These may be at road and fence intersections or along a road or a fence, at the highest point of a ridge, or the lowest point of a valley. They should also be clearly marked so as to be perceptible for some distance from any direction. Various methods have been used. The blazing of a nearby tree or post on three sides is not very satisfactory for the promiscuous use of the axe is likely to be objected to by the land owner, and the implement is burdensome. The best results have been obtained by painting large crosses on three sides of a nearby tree or post at about six feet from the ground, the point at which the elevation was taken being noted by a white dot and arrow, and the elevation or station number painted on a nearby surface. Public surveys usually mark up the correct elevation while private surveys usually record the station number or the elevation in code so that the work cannot be used by a competitor.

Where the work is to be done with an aneroid, numerous bench marks should be established throughout the area, to enable a frequent checking of that instrument. Where the work is carried on with plane table and telescopic alidade, it is rarely necessary to spend time establishing bench marks unless the area to be mapped is large, in which case an occasional bench mark, previously established, facilitates the work.

Method of Determining Elevations.—Aneroid barometers are used rather extensively in detailing certain areas. They are subject to numerous errors and their use is probably justified only under certain special conditions. They have the advantage that they require only one man for their use. When, then, it

becomes absolutely necessary for a man to detail an area without an assistant the aneroid may be used. It can also be used in thick timber, where it is practically impossible to use any other instrument to advantage.

All elevations determined with the aneroid should be recorded on the map, exactly as in work with the alidade, to be described later. The correct locations for plotting elevations are usually determined by pacing and pocket compass, or estimated with reference to the land lines. The same precautions regarding the following of outcrops should be observed as in other types of work. Commonly aneroid elevations should be checked one or more times before permanent recording.

The precise level has occasionally been used in detailed structure mapping, but owing to the large number of set-ups required, and to the fact that it is of no value in determining locations, its use is very slow and not economical.

The transit has also been used in such work. Its principle of use is the same as that of the telescopic alidade, except that notes cannot be plotted in the field, which renders it less valuable for this kind of work. It is far more cumbersome and less useful than the plane table and telescopic alidade.

The telescopic alidade and plane table comprise the most generally satisfactory method of detailed structure mapping, because they take care of determinations both of elevation and location, are rapid and accurate, and allow the plotting of results in the field as the work proceeds. Details of the use of the instrument are given in a preceding chapter.

Preliminary Scouting.—If a preliminary reconnaissance has not been made, or if it has been made by someone other than the man who is to do the detailed work, the first step in detailing an area should be to "scout" the region rapidly to get the general "lay" of the structure, to note where exposures are most numerous, to determine the general magnitude of the structure in order to be able to choose the proper scale and interval to be used, and to plan the work.

Scale and Contour Interval.—For most structures in the Mid-Continent Field, 4 in. to the mile ($1/15840$), is a convenient scale and a 10 ft. interval has been found to be very satisfactory. One inch to one thousand feet is a scale easily plotted, and much used. In very low structures it may more rarely be advisable to use a 5 ft. contour interval, but anything less than that would appear to be a waste of time, since it is probable that errors of nearly that magnitude commonly enter into the field work, chiefly through inability to locate more closely the exact top of the bed on which the observations are being taken. This condition may result from inequalities in deposition, or from later slump. The inch scale ($1/62500$) and 50 ft. or 100 ft. intervals may meet the requirements in more intensely folded regions, like parts of Pennsylvania or Wyoming.

Measuring Detailed Sections.—It may be advisable, before starting actual mapping, to measure one or more detailed sections, in order to learn the character and thickness of the rocks involved, and to determine accurately the intervals between the horizons on which elevations are to be taken. More often the geologist, with this requirement in mind, measures the intervals as favorable points are reached during the regular work of detailing. Points are sought where the horizontal distance between the outcrops of two beds is a minimum, their elevation taken by means of the alidade, and a permanent record thereby made in the notes and on the map.

MAKING THE FIELD MAP

Mapping will usually begin in the easiest part of the area where outcrops are most abundant, that one may become more familiar with the key beds and obtain the intervals before working in the more difficult portions of a region. It may also be found desirable to start on the regional dip side of a structure as that is the least critical part.

Set-ups.—The placing and orientation of the plane table and alidade is usually called a "set-up." In general such points

should be so chosen that the greatest area can be single location. This necessitates good judgment of the instrument man and for the best results calls edge on his part of the general plan of work, so that l his set-ups where the greatest extent of outcrop of t can be seen. As a rule such a point will be on a p top, especially if the key bed outcrops well up on but sometimes will be in the center of an open valle outcrop can be seen on both sides. Care should to avoid the vicinity of trees and brush that may i the line of sight. The choice of poor or good set-u greatly hinder or facilitate the work.

Following the Outcrops.—After it has been d start in any given place, the instrument man cho from which he can see some section corner or ben which the start is to be made, and at the same tim of as large an area as possible. The geologist, carr follows the outcrop of a chosen key bed, and, w sible, gives the instrument man as frequent rea essential to the degree of detail desired. In order t components of the dip at right angles to each oth are taken at the ends of points and at the heads of general it is advisable to take elevations on two hor ing their interval frequently, in order to verify th When as much area has been covered as can be the set-up, the rodman signals turning-point, turning-point on the outcrop if convenient to do an extra sight. Turning-point sights should not those allowable for side-sights, and should be the position of the next set-up in mind. The ins now goes to the place designated, sets up the tabl point, and backsights on the turning-point to d location and height of instrument.

Cautions to be observed by the geologist in follo crop are outlined in the preceding chapter.

Information to go on the Map.—Three types of information should be recorded, at least in part, on the field sheet. (See sheet of symbols.) These are culture, topography, and structure. Culture, that is the works of man, includes houses, roads, section corners (and frequently property lines), oil and gas wells, pipe lines, tanks, etc. With the exception of section corners and wells, these are usually located approximately by triangulation, the rodman having no part in this work. Wells and land corners should be located exactly. The only topographic feature usually recorded is drainage, the chief value of which is in interpreting structure, but which can be used for location of water supply, and as an aid in checking positions.

Structural information requires the greatest care in recording. All stations, including turning-points, set-ups, and side-sights, should be numbered in the notes, and these numbers should appear at the proper place on the field map. The actual line of sight between all stations should preferably be drawn on the map with solid ruled lines, so that it is possible to see at a glance the location of the stations. Some prefer not to draw in the lines of sight as it makes the appearance of the sheet less neat, but unless they obscure necessary data it is better that they be drawn, as they assist the geologist in studying the map. In general the actual elevations of the stations are penciled on the map under the proper station number. It is less confusing if the elevations of points not on outcrops be omitted from the map. In any case, whether elevations are recorded or not, the instrument man should keep his computations up to date, so that the geologist may at any time compare the elevations of any points. A few geologists prefer not to have elevations recorded in the field, for fear of information getting into the hands of competitors.

The actual trace of all outcrops of key beds should be drawn on the map. If there are several such, they may be differentiated by lines consisting of different combinations of dots and dashes.

In order that a map shall not become too blurred or mussed,

it is good practice for the instrument man each night, or at rather frequent intervals, to ink in all informatio is known to be correct. Some prefer to use a differe of ink for each feature, but colored inks fade badly exposures to the sun, so that it is usually preferable to u black, differentiating the outcrops by various types of li

The drawing of structural contours can best be dor the geologist has clearly in mind the details of all stati visible dips and the topography; and should never be more than a few days.

Closure.—It is good practice to "check in" as frequ convenient, to see that no errors have been made. A may be closed upon itself or upon some point of known and elevation, but the former is more often the procedu cases where there is a suspicion that the instrument man fying his record to cause a proper closure, the geologist ma test the matter by "shooting him off," *i.e.*, sighting him point other than that on which he is supposed to close, e elevation or distance. This discrepancy may be closely ated and if the instrument man makes a perfect closure hi cation is easily detected. However humiliating it may be distrusted, the instrument man should hardly resent test, for his work should be reasonably correct and when proved his ability he will not be so tested.

It is sometimes possible to determine the elevation widely visible point, such as the top of a derrick, win house, and make frequent approximate checks by sighti from various points. (See also pp. 127–128.)

Errors in reading plus for minus and minus for plus and other larger blunders in computations can usually be at once by the geologist, if he is watching as he should, the lay of the structure. For this reason if for no other, the ment man should keep all his computations strictly up minute.

The geologist should also frequently check intervals possible, to verify his correlations.

KEEPING OF NOTES

Instrument Man's Notes.—The form of notes kept by the instrument man varies but little, the data being always the same. It is good practice to put down all observations as taken and make the computation, even if small, afterwards. If this is done all errors of computation can be found and corrected.

Two sample pages of notes, showing approved forms are given herewith. The first is a form used by the United States Geological Survey and represents a method of keeping notes when using the Beaman stadia arc; the second is a form used by the authors and represents a method of keeping notes when using the gradienter screw or the stepping method. Both forms are equally applicable for all methods of determining elevation, the vertical angles, however measured, being placed in the same column and never confused with each other. The Beaman stadia arc angles are comparatively large numbers consisting always of two figures; the vertical arc readings are recorded as degrees and minutes; the drum and stepping angles by a small number with a plus or minus sign before it.

In the authors' form of notes (p. 192), the first column gives the character of the station and its number. The circles before the figures 1, 3, and 8 show that these stations were turning-

A FORM OF NOTES FOR USE WITH BEAMAN STADIA ARC, AS USED BY UNITED STATES GEOLOGICAL SURVEY

(After W. & L. E. Gurley)

Stadia arc reading		Distance	Product	Rod correction	Difference of elevation	Elevation	Station
B.S.	F.S.						
						654.7	B.M.
54	..	4.2	− 16.8	+ 8.2	− 8.6	646.1	H.I.
..	48	6.3	− 12.6	− 4.9	−17.5	628.6	T.P.
44	..	9.2	+ 55.2	+ 4.3	+59.5	688.1	H.I.
..	57	15.8	+110.6	−13.8	+96.8	784.9	T.P.
50	..	8.4	....	+ 6.7	+ 6.7	791.6	H.I.
..	50	5.6	....	− 9.8	− 9.8	781.8	T.P.

SAMPLE FROM INSTRUMENT MAN'S NOTES

Date, **Jan. 25, 1918.** Rodman, **R. N. Barnett.**
Location, **Osage Co., Okla.** Instrument man, **O. C. Bailey.**

Sta.	Dist.	V.A.	Rod	D.E.	H.I.	Elev.	Bed	Remarks
⊙1	....	...	....	......	.....	682.0	..	U. S. G. S. B. M., NW. Cor. 22–22–10.
Δ2	1100	+1	3.6	− 7.4	674.6			
⊙3	1400	−2	7.8	−35.8	.....	638.8	10	
Δ4	1350	−1	5.0	+18.5	657.3	.....	9	−4 ft. for crop.
5	8.5×2 1700	−1	6.5	−23.5	.....	634.0	10	
6	9.8×2 1960	−1	10.0	−29.6	.....	628.0	10	
7	10×2 2000	−1	L8.0 18.0	−38.0	.....	619.0	10	
⊙8	9×2 1800	+2	6.8	+29.2	.....	686.6	11	

points; the triangles before the numbers 2 and 4, that they were instrument stations. All stations including instrument stations, are numbered consecutively as taken. Some prefer to designate the instrument stations or set-ups by letters and the other points by numbers. Thus, the stations taken from the first set-up would be numbered A_1, A_2, A_3, etc., and those from the second, B_1, B_2, B_3, etc. Some employ even more complicated systems.

The second column shows distance. Some prefer the heading "S.I." (stadia intercept), but inasmuch as all distances are not determined by means of the stadia, the heading "Distance" is preferred. Note that when half-stadia intercepts were read, as in Nos. 5, 6, 7 and 8, both the half and the full intercepts are recorded. It is rarely, if ever, necessary to use a column for corrected distance. Usually angles of less than 6° need not be corrected for horizontal distance, and greater angles are very rare in petroleum field work. In such rare cases the correct horizontal distance may be entered in the same square as the approximate distance.

In the third column, marked "V.A.," for vertical angle, are recorded all angular measurements for securing vertical distance, whether taken in degrees, divisions of the Beaman stadia arc, or rotations of the gradienter screw. Unless the number itself shows it, they should be preceded by a suitable sign, such as + or −, to show whether the station sighted upon is higher or lower than the instrument (H.I.).

The fourth column, marked "Rod," is for elevation rod readings. At the seventh station the rod reading of the lower stadia wire was used and that of the horizontal wire computed. Some prefer to use two columns for rod readings, one for foresights and one for backsights.

The fifth column, marked "D.E." (difference in elevation), is for the computed difference in elevation between the axis of the telescope (H.I.) and the point on which the rod was held. Its chief value lies in the fact that it furnishes an intermediate stopping point in the calculations.

The sixth column, marked "H.I.," is the height of the axis of the telescope. As the "H.I." enters into all computations, it is made conspicuous by giving it a separate column.

The seventh column, marked "Elev.," is the computed elevation of the point upon which the rod was held.

The eighth column, marked "Bed," is for the recording of the bed number, each horizon traced being given a distinctive number or letter, so that the records will show upon which stratum each elevation was taken. It is believed that the use of numbers for beds is more flexible than the use of letters or names. If the first bed is numbered 10, the next one above 11, the first one below 9, etc., and it is then desired to use a bed between the ones numbered 10 and 11, it may be called 10.5. Numbers can be added indefinitely at any point but will always show the relative position of all the beds used.

The ninth column, marked "Remarks," is for recording any desirable information concerning the sight. This includes description of bench marks, stations, corrections for elevation and distance as reported to the instrument man by the rodman, and in fact everything essential not otherwise provided for.

The headings are arranged from left to right in the order in which the observations and computations are usually made.

Geologist's Notes.—The geologist must be able to report to the instrument man, whenever convenient, which bed, if any, each sight was taken upon. If notes are kept, they will consist chiefly of such data as measured sections, intervals, and thickness and character of key beds. In general it is best to enter all essential information under "Remarks" in the instrument man's notes, in order that all the information may be kept together. In reconnaissance work, especially in new districts, complete notes should be taken, essentially as complete as would be taken in a general reconnaissance for an areal geology report.

THE FINISHED MAP

Reduction of Elevations.—If all elevations are taken on a single key bed, the contours may be drawn at once through points of equal elevation. If more than one key bed has been used, it will be necessary to reduce the observations to a common datum plane. It is first decided what bed shall be used as the datum to which the structural contours are to be referred. As a rule it makes little difference what bed is chosen unless it is desired to compare this given structure with others in adjacent regions, in which case it is almost necessary to use a common datum plane for the entire area. Labor is eliminated if that horizon is chosen on which the largest number of elevations were taken directly in the field; and this will usually be that horizon which outcrops best, is exposed over the largest area, and has the most constant characteristics. If the area is large, it not infrequently happens that the datum horizon is deeply buried in some places and removed by erosion in others. In the case of those elevations taken on beds lower than the chosen reference bed, the reduction is made by adding the measured or computed interval between them. In case of elevations on members above the datum horizon, the interval is subtracted.

The determination of these intervals is of the utmost impor-

tance and constitutes a frequent source of error with beginners. They are in part measured in the field and in part computed from the field data. It should be clear that the nearer the outcrops of the two beds are to each other horizontally, the more accurately the interval can be measured as this eliminates change in elevation due to dip. The most favorable case is one in which two beds of low dips are exposed on a steep hillside, one below the other, in which case the difference of elevation is the interval. Such cases rarely occur. Where the outcrops are more widely separated, one theoretically has the choice of two methods to avoid changes in elevation due to dip. One is to choose two points of known elevation, one on each bed, and on the same line of strike, whereupon their difference in elevation is the desired interval. The other method is to choose three points of known elevation, two of which are on one bed and one on the other in the same line of dip. Then assuming the dip as determined by the two elevations on one bed to be constant, the elevation of a point on this bed directly under or over[1] the third point is computed. The difference in elevation between this and the third point is the interval.

Naturally, two points in the same line of strike, or three points fairly close together and in the same line of dip are seldom obtained, both because the line of strike changes, and because of the difficulty in determining strike. It may therefore require considerable ingenuity to obtain satisfactory intervals. Often trial intervals taken at different points agree so closely that their average may be used. Where much difficulty is experienced, the best approximation may be obtained by contouring each stratum separately about the points to be used. Then by extending the contouring with additional lines of such shape and spacing as may be indicated by those already drawn, the two horizons are brought together until some point is covered by both sets. The difference in the value of the two sets for this point is the interval. This method is based on the assumption

[1] If the angle of dip is large this point should be defined by a lineperpendicular to the beds, passing through the third point.

that the dip between the points is constant and equal to the observed dip in the vicinity. In the use of either method, an area should be chosen in which the dip and strike are as nearly constant as can be found, and it is often advisable to check one method by the other.

After the interval has been determined and the elevations corrected thereby, it is good practice to put the corrected elevations in ink on the field sheet, in parentheses, below the observed elevations so they will stand out clearly. The bed with only one set of elevations is the datum horizon.

In making the above corrections care must be used to apply the proper variation, if the interval is not constant over the area mapped. This variation is not infrequently very marked and falure to take it into account in reducing to common datum might seriously impair the value of the work. Variations of this type are often plotted by means of a convergence sheet, prepared on transparent paper, on the same scale as the structural contour map. The convergence sheet, or isochore chart, has marked upon it all observed data concerning the interval between the bed on which observations were taken and the final datum horizon. Using this data, lines are drawn through points of equal interval on the isochore chart. This chart is then laid on the structural map, and shows the interval to be used at any desired point. This plan is sometimes used for completing field sheets, in cases in which elevations are taken on numerous horizons, but it is in more general use for plotting structural contours on a producing sand from a combination of well data and surface observations.

Contouring.—After these elevations are all reduced to terms of the datum horizon, the contours are drawn and inked in. Structure contouring preceeds cautiously, the easiest part of each line and the easiest part of the structure being first shown. These by their spacing and their shape indicate the position that will be occupied by the adjacent lines in so far as it is consistent with the elevations.

The contour lines are started at the points where the dip is the

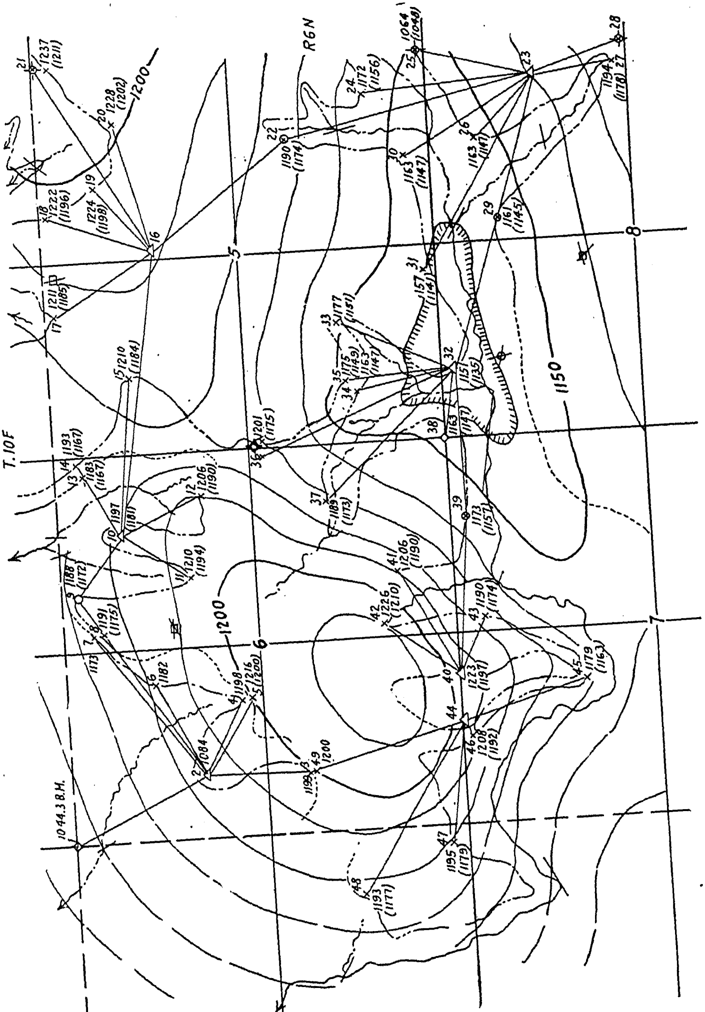


FIG. 50.—Completed field map.

most regular, where the elevations are the most numerous and where the geologist has a good knowledge of conditions from his field observations.

The map then first consists of a number of short discontinuous lines which, as they are added to and extended, build up into the finished map. In so far as permitted by elevations and observed dips, the curvature and spacing of the contours are then adjusted to show such a surface of uniformly changing curvature as one would expect to be formed by such folding.

In case very sharp irregularities are noted in the trace of the contours, the data should be examined closely for errors, because, except as a result of faulting, the curves of folds are likely to be rather smooth and gentle. A single inconsistent observation not corresponding with any structural feature noted in the field, will usually be discarded. If several such occur, it is usually best to return to the area and try to discover the cause. If the computations have been kept up to date, and always entered on the map as fast as completed, such inconsistent elevations should be noted in the field as the work proceeds. In fact, this is the chief reason for insisting that an instrument man keep his computations up to date. Figure 50 illustrates a completed field map.

The Tracing.—The most essential features on the tracing or blue print that is to be submitted to the client are the structural contours and the property lines, and these should be emphasized on the final copy by heavy line drawings. Roads and houses, dry holes, oil and gas wells, pipe lines, and tankage may be entered when present, as may also the outcrops of beds on which elevations were taken. In so far as this information has been obtained, it should be included in the tracing providing the legibility of more important data is not thereby impaired. Actually observed elevations are usually not entered on the final map, but may be used if they do not make the map too crowded.

THE FINAL REPORT

The character of the report will vary with the detailed or reconnaissance nature of the field work, with the amount of

development in the area, and with the character of the parties to whom the report is to be submitted, so that a definite outline can hardly be given. A few of the more important topics are mentioned below.

Location.—In all cases the exact location of the lands should be given, in terms used by the land surveys, usually section, township, and range. In unsurveyed territory in the public land states areas should be described as closely as possible with reference to natural features, so there can be no possibility of mistaking the locality if it is decided to file on the lands.

Topography.—As a rule, the topography of the area should be indicated briefly, particularly in regions not familiar to the persons for whom the report is made, as it has a distinct bearing on ease of accessibility, on transportation and pipe line problems, and on water supply. In some cases topography will influence location by determining differences in depth of drilling, but only when the location which is most favorable topographically is also quite as favorable as any other structurally.

Stratigraphy.—As a rule, the age and character of the rocks, and frequently the local formation names, should be given. Also a list of the known or probable oil and gas sands with probable depths and thicknesses.

Structure.—The map should show and the report should include the exact location of all anticlines, terraces, faults, or other structural features that might influence accumulation; the general shape, amount of closure, and position and direction of crest of all anticlines; the contour interval; the datum plane; and the direction and amount of displacement of faults, together with their probable effect on accumulation. The other horizons on which observations were taken and the reduction intervals are often described.

Oil and Gas Sands.—The number, names, depth, thickness, and character of oil and gas sands should be given, so far as possible, with any information available as to water condition. In developed areas, this information can be given in much detail. In wildcat areas, very little is usually known of the sands, but

the possibilities should be set forth as clearly as the information will permit.

Development.—In reporting on developed properties, careful attention should be paid to the number, depth, and character of producing wells, with as many logs as can be secured. Initial production, settled production, shooting, water conditions, time and rate of pumping, rate of decline, and similar data are of the greatest importance. Dry holes are often cleverly concealed on the ground, but should be sought for carefully and their depth and location given. Tankage and pipe line facilities should be set forth.

Fuel.—Character and cost of fuel for drilling should be considered, especially in wildcat territory. Gas, oil, coal, and wood all serve in various localities. In areas far from railroad, particularly in the arid parts of the west, fuel is a serious problem. Kind of fuel, distance to be hauled, available amount, and cost delivered should be determined.

Water Supply.—Proximity of water for drilling is important, and the amount available, its permanence, and the distance it must be hauled or pumped should be indicated.

Transportation.—The name of railroads, distance from railroad, character of public roads, and relief of country are important factors, and the possible locations for pipe lines should be considered.

Labor and Local Supplies.—In remote parts of Wyoming, Utah, and similarly situated states, the question of local labor and local supplies is a serious one, and where unusual scarcity or high prices prevail, mention should be made of such conditions.

Recommendations.—Recommendations include many sets of conditions. Of fundamental importance is the statement of the possibility of the presence of oil or gas. Advice to lease, purchase, or file will often include also limitations as to advisable expenditure. Advice to drill will usually include the making of a location. All recommendations should recognize as nearly as possible the elements of chance in the proposed venture, together with the probable reward if successful.

A geologist is undoubtedly justified in considering the character of his client in determining to advise favorably or unfavorably in a given case. It is certainly proper to advise risks for a large concern, which would not be justified for a party with limited means, who might become bankrupt through one or two failures.

GLOSSARY[1]

Aberration—is of two types.

1. White light, in passing through a lens (*q v.*), has its constituent colors refracted (*q.v.*) unequally, each color being brought to a focus at a different point. This is chromatic aberration. *See* index.

2. Rays of light which pass through the edges of a spherical lens are not focused at the same point as those passing through the center. This is spherical aberration. *See* index.

Abney level—a hand level (*q.v.*) with clinometer (*q.v.*) attachment, invented by Captain Abney, of the British Army. *See* index.

Absolute humidity—see humidity.

Accumulation—here used to indicate that process by which oil and gas within the ground migrate into the more porous formations and there collect in quantity.

Acline—beds without dip; unfolded; in a horizontal position.

Adjustment of instruments—the act of correcting an instrument that reads incorrectly. *See* index.

Aeolian—*see* eolian.

Agglomerates—fragmental igneous (*q.v.*) rocks, such as tuffs (*q.v.*) and volcanic breccias (*q.v.*), that have been produced by violent explosive eruptions. The term is also used for any fragmental rock which has been cemented by lava (*q.v.*). *See* also pyroclastic.

Agonic line—the line of no magnetic declination (*q.v.*); the line passing through all points at which the magnetic needle points to the true north. *See* also isogonic chart.

Algonkian—the second period of the Proterozoic (*q.v.*), or pre-Cambrian (*q.v.*) era. The rocks are dominantly sedimentary, but in many places are cut by large igneous intrusions (*q.v.*), and, as a rule, are much folded, faulted, and metamorphosed (*q.v.*). Oil and gas have not been found in commercial quantities in Algonkian rocks.

Alidades—are of two types.

1. The open sight or ruler alidade, used simply to plot bearings (*q.v.*) on an oriented (*q.v.*) table.

[1] The letters (*q.v.*) indicate a cross reference to the word after which they appear.

2. The telescopic alidade is used in the same way to plot bearings, but as it carries a telescope, is also used to determine distance and elevation.

See plane table, transit, Beaman stadia arc, vertical angle, stadia, etc. Also *see* index.

Alluvium—river borne sediments, such as the gravels, sands, and silts of flood plains.

Aneroid—a barometer (*q.v.*) used to measure atmospheric pressure (*q.v.*) by means of a vacuum chamber, the variations of which are shown by means of a pointer and dial. *See* index.

Angular unconformity—an unconformity (*q.v.*) in which the beds below the unconformable contact had undergone folding and erosion before the upper beds were deposited. The lower beds are therefore the more folded and are not parallel to those above. *See* index.

Antecedent stream—a stream which has held its course across some uplift, such as a fold (*q.v.*) or fault (*q.v.*), cutting down as fast as the uplift took place, and not being diverted. It antedates the structure which it crosses.

Anticlinal mountains and valleys—mountains and valleys that occupy the sites of anticlines. *See* also synclinal mountains and valleys.

Anticline—an upfold or arch in the rocks. As a rule the beds dip outward in two or more directions from the crest. *See* index.

Anticlinorium—a major anticline, on the flanks of which are superimposed smaller synclines (*q.v.*) and anticlines; a composite fold (*q.v.*).

Apparent dip—If dipping beds are seen in any section other than one at right angles to their strike (*q.v.*), the observed dip (*q.v.*) is less than the true dip and is not in the direction of the latter. Such a condition gives apparent dip. *See* index.

Archean—a period of the Proterozoic (*q.v.*) or pre-Cambrian (*q.v.*) era; the oldest known rocks. Dominantly igneous (*q.v.*), but containing small amounts of highly metamorphosed (*q.v.*) sediments. Do not yield oil or gas in paying quantities.

Arkose—a highly feldspathic sand or sandstone; a rock which has resulted from the incomplete weathering of an acid igneous (*q.v.*) rock; such as a granite (*q.v.*).

Arrested anticline—a term used by some to describe what is usually called a terrace (*q.v.*).

Asphalt—a natural solid, or viscous mixture of partially oxidized hydrocarbons (*q.v.*). Usually dark brown or black in color, melts at 90° to 100°F., and is to a large extent soluble in oil of turpentine, ether, or alcohol. Occurs as seeps (*q.v.*), springs, lakes, and as impregnations in rocks.

Asphaltic—containing, or consisting of asphalt.

Asphalt-base petroleum—Asphalt-base petroleums are those which yield an asphalt residue on evaporation or distillation as contrasted with those that yield paraffin (*q.v.*).

Asphalt rock—a rock impregnated with asphalt. Usually the result of the evaporation of the lighter constituents of petroleum (*q.v.*).

Asymmetrical fold—any fold (*q.v.*) the limbs of which do not dip at equal angles in opposite directions.

Axis of a fold—a line determined by the intersection of the two limbs of a fold (*q.v.*) on any given bed at crest (*q.v.*) or trough (*q.v.*). A line defined by the intersection of any bed and a plane bisecting the angle between the limbs.

Azimuth—an arc in a horizontal plane; the angle any course of a traverse (*q.v.*) makes with the meridian as measured clockwise, usually from the south.

Back-lash—lost motion in working parts of an instrument resulting from mechanical wear of the parts or imperfections in workmanship. *See* index.

Backsight—a sight upon a known point to determine the position or elevation of the instrument. *See* also set-up, foresight, and turning-point.

Barograph—a self-recording barometer which traces on a roll of paper a graph of the pressure variations.

Barometer—an instrument for recording air pressure, and since air pressure varies with elevation, also used to determine elevations. There are two general types, the mercurial (*q.v.*) and the aneroid (*q.v.*) barometers.

Baumé System—Density of oil is usually measured in degrees Baumé. The instrument used was invented by a French chemist Baumé, and consists of a sealed hollow tube with standardized graduations, which is floated in the oil. The heavier the oil the less distance it sinks and the lower the reading and *vice versa*. *See* specific gravity.

Beaman stadia arc—a vertical arc graduated in divisions representing simple whole numbers of the function $\frac{1}{2}$ sin $2v$ of the vertical angle. *See* index.

Bearing—the direction of a line as referred to the cardinal points of the compass, such as N. 10° E., or S. 45° W.

Bedrock—solid rock, or outcrop, as contrasted with soil, float (*q.v.*), etc.

Beds—rock layers separated by planes of parting called bedding planes. In common usage, bed is often incorrectly used as a synonym of stratum (*q.v.*). *See* also formation and member.

Bench mark—a point of known elevation so marked that it can be again found and used. *See* index.

Binocular hand level—a hand level with two sighting tubes. *See* index.

Bitumen—a mixture of native hydrocarbons, such as natural gas (*q.v.*), petroleum (*q.v.*), asphalt (*q.v.*), and the like.

Bitumenous shale—a shale impregnated with bitumenous matters. *See* also oil shale.

Brea—soil impregnated with the heavier substances left from evaporation of petroleum seeps (*q.v.*).

"Break-over"—a term used locally in certain regions to indicate a rounded crest which is both structurally and topographically high.

"Breaks"—(1) a term applied locally to small faults; (2) also applied locally to soft layers within hard ones, such as "shale-breaks;" (3) also used to indicate any sudden change in topography, as from a plain to a hilly country, *viz.*, the Breaks of Missouri River.

Breccia—a rock consisting of angular rock fragments, cemented together. It often consists of the crushed rock along a fault (*q.v.*).

Brunton—a type of compass (*q.v.*) provided with clinometer (*q.v.*) and devices for reading vertical angles (*q.v.*); commonly called a "pocket transit." *See* index.

Bubble-tube—a tube partially filled with a liquid in which is a bubble. Used for levelling. *See* index.

Bull's-eye level—a level, the inner upper surface of whose bubble-container is ground to a sphere of large radius. *See* index.

Calibrate—to determine the accuracy of the readings of an instrument.

Cambrian—the earliest period of the Paleozoic (*q.v.*) era. The rocks of this period are almost wholly sedimentary (*q.v.*) and largely marine (*q.v.*) in the United States. Small quantities of gas are reported from Cambrian beds, but neither oil nor gas in paying quantities has ever been found.

Cap rock—the more impervious cover (*q.v.*) found above a porous oil or gas bearing bed.

Carbonaceous—containing carbon, usually of organic origin, such as shales with plant remains.

Carbon dioxide—a colorless and odorless gas of the composition, CO_2. It escapes from the earth in various localities, and should not be confused with "natural gas" (*q.v.*).

Carboniferous period—the latest period of the Paleozoic (*q.v.*) era, divided into the Mississippian (*q.v.*), Pennsylvanian (*q.v.*) and Permian (*q.v.*) epochs. Formations of the Pennsylvanian and of the Mississippian produce oil and gas in commercial quantities, and to some extent, those of the Permian.

Cement—the binding materials of sedimentary rocks (*q.v.*), especially sandstones (*q.v.*). Usually consists of calcium carbonate, silica, or iron oxide.

Cenozoic era—the latest era of geologic time, divided into the Tertiary (*q.v.*) and Quaternary (*q.v.*) periods.

Checker boarding—the division of property in such a way that two parties take alternating parcels of land.

Chert—a compact, very fine-grained rock consisting of silica (SiO_2) with varying proportions of water and impurities. The porosity of chert is very low. Also called flint.

Chromatic aberration—*see* aberration.

Clay—a fine grained material, consisting chiefly of kaolin mixed with fragments and particles of other minerals, possessing plasticity when wet and becoming hard when dry.

Clinometer—an instrument for measuring the dip of rock beds or topographic slopes. *See* index.

Closed pressure—the pressure on a gas well that has been closed long enough to attain a maximum. The time is usually about 24 hours, but is sometimes several days. The well must stay closed until the pressure does not increase more rapidly than 1 per cent. in 10 minutes, before the pressure is gauged. *See* open pressure.

Closure—(1) the vertical deformation (*q.v.*) of a fold, or the vertical distance between the anticlinal crest and the point of drainage. An anticlinal fold that closes six ten-foot structural contours (*q.v.*) has over 50 and less than 70 ft. of closure; (2) in instrument work, a term used to indicate "checking in" or closing a circuit, by checking on some known point. *See* traverse. Also *see* index.

Coal oil—a term variously applied to products of distillation of coal; less correctly used for crude petroleum and for kerosene.

Collimation, line of—the line of sight of the telescope of a surveying instrument, as defined by the axis of the objective (*q.v.*) and the intersection of the cross-wires (*q.v.*), when they are in perfect alignment. *See* index.

Compass—a compass consists essentially of a magnetized needle, mounted on a pivot, and free to swing in a horizontal plane. It is usually pivoted at the center of a circle graduated to degrees, and is used for determining directions. *See* in ex.

Composite fold—a major fold (*q.v.*) upon which have been superimposed minor folds.

Concretions—aggregates of mineral matter, usually rounded, and often of concentric structure, which have grown up about some nucleus.

Conformity—continuous sequence of beds, without break, as contrasted with unconformity (*q.v.*).

Conglomerate—also called pudding stone. A rock made up of worn and rounded pebbles of other rocks, cemented together; a consolidated gravel.

Consequent stream—a stream which originates on a newly upraised surface, and which takes the particular course it does, as a result of the slope of the newly risen land.

Contact—the plane along which two strata (*q.v.*) or formations (*q.v.*) are in contact.

Contemporaneous erosion—slight local erosion which goes on while elsewhere deposition is continuous. *See* also unconformity.

Continental deposits—deposits laid down on land by rivers, wind, glaciers, etc., in contrast to sediments laid down in the ocean. *See* also terrestrial deposits and marine deposits.

Contours—Contours are of two types, topographic and structural. Topographic contours are imaginary lines on the surface of the ground, drawn at regular intervals through points of equal elevation. Structural contours are such lines on the surface (not erosion surface) of a given bed, through points of equal elevation. Topographic contours show the configuration of the land surface, structural contours the configuration of the rock folds. The contour interval is the difference in elevation as represented by two adjacent contour lines. *See* structural contour and isobath. *See* also index.

Convergence—Owing to the thickening and thinning of intervening beds, as a result of unequal deposition, the vertical distance, or interval, between certain beds may change sufficiently to have considerable influence on the plotting of structural contour lines. This variation of interval is known as convergence. *See* isobath, isochore, and iso-pachous lines. *See* also index.

Copperas dirt—*see* "sour dirt."

Correlation—the process of determining the equivalency or non-equivalency of beds in separated outcrops. *See* also stratigraphy. *See* index.

Cover—the impervious (*q.v.*) layer overlying an oil or gas sand, which prevents the upward escape of the oil or gas.

Creep—the slow movement of soil and loose rock down a slope under the combined influence of gravity, frost, and ground water. The edges of rock beds which have suffered creep may appear to show considerable dips.

Crest—the highest part of an anticline (*q.v.*), or the line (the point in the case of a dome) from which the beds dip outward. *See* also trough and syncline.

Cretaceous period—the latest period of the Mesozoic (*q.v.*) era. In the United States, Cretaceous rocks are chiefly sedimentary (*q.v.*), in part marine (*q.v.*) and in part terrestrial (*q.v.*). They yield valuable quantities of coal, oil, and gas.

Crop—a local abbreviation of the word outcrop (*q.v.*).

Cross bedding—also known as false bedding. Stratification inclined to the true bedding and often confused with the latter. Characteristic of sandstones.

Cross-wires or hairs—the wires or hairs crossing at right angles in microscopes and surveying telescopes, in the exact line of the optic center of the instrument. *See* index.

"Crude" or crude oil—the natural petroleum, unrefined, as it issues from the ground.

Cuesta—an asymmetrical ridge, the gentler slope of which is controlled by, and is parallel to, the dip of a hard layer of rock and is known as the dip slope (*q.v.*). The other and steeper slope, caused by undermining and sapping (*q.v.*), is known as the escarpment (*q.v.*) slope. *See* index.

Cuttings—the rock particles bailed from a drilled well.

Datum horizon—any horizon used as a reference for elevations. For most topographic work the datum plane is mean sea level. In structural mapping, the bed, or horizon, to which all elevations are finally reduced is called the datum horizon, or key bed (*q.v.*). *See* index.

Declination—the variation between the magnetic and the true north.

Decline—the decrease in yield of an oil or gas well. The first yield is called the "flush" (*q.v.*) production. For a while the decline is rapid, becoming more steady until "settled" (*q.v.*) production is reached. Decline curves are curves in which yield is plotted against time, showing graphically the change in rate of production

Deformation—the result of folding (*q.v.*) or faulting (*q.v.*).

Degradation—erosion or wearing away of the land surface.

Denudation—the general lowering of the land surface through erosion.

Deposition—the act of depositing; settling out. In geology, the laying down of sediments (*q.v.*); sedimentation.

Desiccation—the drying out of sediments; loss of water by drying, with consequent shrinkage.

Detailed work—the making of a thorough, as contrasted with a hasty, examination of an area. Detailing usually involves the making of a structural contour (*q.v.*) map. *See* also reconnaissance. *See* index.

Development—any work which actively looks toward bringing in production, such as erecting rigs, building tankage, drilling wells, etc.

Devonian period—the fourth period of the Paleozoic (*q.v.*) era, preceded by the Silurian (*q.v.*) and followed by the Carboniferous (*q.v.*). Devonian rocks in the United States are chiefly marine (*q.v.*) sediments, though terrestrial (*q.v.*) beds are extensively developed in the northeast. Considerable oil and gas are yielded by Devonian formations in eastern United States.

Diatoms—microscopic plants that secrete silicious material. Their accumulation produces diatomaceous earth. It has been suggested that a portion, at least, of the Californian oils have resulted from the organic matter of diatoms.

Dike—a tabular mass of igneous (*q.v.*) rock filling or intruded along a fracture in other rocks.

Dip—the maximum angle of inclination, at a given point, between the dipping bed, or plane, and the horizontal. This maximum angle is necessarily at right angles to the strike (*q.v.*).

Dip slope—a slope which is parallel to, and controlled by, the surface of a hard layer of dipping rock. *See* also cuesta and escarpment. *See* index.

Dip valley—a valley trending in the direction of the general rock dip of the region. Also known as a transverse (*q.v.*), or crosswise valley, in contrast with a strike valley (*q.v.*).

Disconformity—a term used in varying senses for certain types of unconformities (*q.v.*), but generally to describe those in which the beds below and above the unconformable contact are parallel, that is the unconformity is not angular (*q.v.*). Others employ it to describe a stratigraphic break which results from non-deposition, with no erosion whatever.

Dislocations—another term for faults (*q.v.*).

Displacement—a term used to describe fault (*q.v.*) movement, and variously defined. Concensus of opinion seems to be that total displacement shall be defined as the distance, measured in the fault plane, between points in opposite walls that were formerly adjacent. Apparent displacement, or simply displacement, is then generally used for the projection of the total displacement onto a vertical plane, normal to the strike of the fault. *See* also throw, heave, etc.

Dissected—cut up by valleys, carved by erosion.

Dolomites—magnesian limestones (*q.v.*) with varying per cents of magnesium carbonate.

Dome—a special type of anticline (*q.v.*) approximately circular or elliptical in plan, the beds dipping outward from a central point. *See* index.

Downthrow side—a term used to describe the apparent relative movement of the walls of a fault (*q.v.*). The side that appears to have gone down with respect to the other is called the downthrow side; the side that appears to have gone up is said to be upthrow.

Drainage—the network of streams in a region.

Drainage point—*see* spilling point.

Drift—glacial (*q.v.*) debris.

Drum—*see* gradienter screw.

Dry hole—somewhat loosely used in oil work, but in general any well that does not produce oil or gas in commercial quantity. A dry hole may flow water, or gas, or may even yield some oil to the pump.

Dry natural gas—a gas that does not contain any considerable amount of easily separated gasoline.

Duster—a dry hole.

"Easts" or east dips—a term used in the Mid-Continent Field to contrast with the general, or regional, dip to the west. Dips in an east direction together with the regional west make up anticlines. Hence, in this field the term is much used. *See* regional dip, west dip, etc. *See* index.

Echelon folds—folds that are in a zone rather than a line so that the end of one may overlap the end of another.

En echelon—*see* echelon.

Eocene epoch—the earliest epoch of the Tertiary (*q.v.*) period. In the United States, Eocene rocks are found on the Coastal Plain where they are both marine (*q.v.*) and terrestrial sediments; in the Rocky Mountains, where they are terrestrial (*q.v.*) with coal beds, and are interbedded in places with

lavas; and on the Pacific Coast, where they are both marine and terrestrial, and yield coal. A portion of the California and Texas oil production is said to come from Eocene beds.

Eolian deposits—wind-deposited sediments, such as loess and dune sand.

Epoch—a unit of geologic time, one of the divisions of a period, as the Eocene (*q.v.*) epoch of the Tertiary (*q.v.*) period, the Pennsylvanian (*q.v.*) epoch of the Carboniferous (*q.v.*) period.

Era—the largest unit of geologic time. Following United States Geological Survey usage, the eras are Proterozoic (*q.v.*), Paleozoic (*q.v.*), Mesozoic (*q.v.*), and Cenozoic (*q.v.*). They are subdivided into periods (*q.v.*).

Erect fold—a fold in which the axial plane (*q.v.*), or plane bisecting the angle between the two flanks, is vertical, or practically so.

Erosion—the general wearing away of the land by wind, running water and other agencies.

Escarpment—a more or less continuous line of cliffs or steep slopes facing in one general direction and due to erosion or faulting. The abbreviated form scarp (*q.v.*) is sometimes used as a synonym, but is more commonly limited to cliffs produced by faulting (*q.v.*). *See* index.

Exposures—bare or uncovered rock ledges. *See* outcrop.

Extrusives—igneous (*q.v.*) rocks that have forced their way out at the surface. Common types are lava flows (*q.v.*) and tuffs (*q.v.*) [consolidated volcanic ash (*q.v.*)].

False bedding—*see* cross bedding.

False dip—cross-bedding or stratification at an angle to the true bedding. *See* also apparent dip.

Fault—a fracture cutting across the rocks, along which there has been a relative slipping of the walls. *See* displacement, throw, heave. *See* also index.

Fauna—the assemblage of animal forms (either modern or fossil) living in a given place at a given time, as for example the Tertiary fauna of the Rocky Mountains. *See* also flora.

Fiducial plate and edge—the base-plate of a telescopic alidade (*q.v.*), and its bevelled edge. *See* index.

Field work—outdoor work, such as reconnaissance (*q.v.*) and detailed mapping (*q.v.*), as contrasted with office work, such as drafting finished maps, writing reports, and the like.

Flint—a variety of chert (*q.v.*).

Float—loose fragments of rock, bowlders, pebbles, and smaller particles; as contrasted with outcrop (*q.v.*) or bedrock (*q.v.*). *See* index.

Flooding—the drowning out of a well, by water, often resulting from drilling too deeply into the sand.

Flora—the assemblage of plants, either modern or fossil, living in a given region at a given time. *See* also fauna.

Flowing well—a well from which oil or water flows without pumping.

Flush production—the amount of oil first produced by a well, as contrasted with the later smaller and more uniform yield, known as settled production (*q.v.*).

Fold—a flexure or bend in the rocks.

Folding—bending or warping of the rocks, the process that forms anticlines (*q.v.*) and synclines (*q.v.*).

Foot wall—a term used to describe the side that lies below an inclined vein or fault (*q.v.*), as contrasted with the hanging wall, which lies above it.

Foresights—all sights by which the location or elevation of points as related to the instrument are obtained, the elevation and position of the latter having been first determined, usually, by a "backsight" (*q.v.*). *See* index.

Formation—a unit of stratified rocks, sometimes simple, sometimes complex, which is of sufficient importance to map separately. Subdivisions of formations, not mapped separately, but given a separate description are termed members.

Fossils—evidences of animal or plant life in the rocks, such as petrified shells, skeletons, leaf and fern imprints, animal footprints, and the like. It is chiefly by the aid of fossils that the age of rocks is determined. *See* correlation and stratigraphic correlation. *See* index.

Fusulina—a small marine fossil, about the shape and size of a grain of wheat belong'ng to the foraminifera. It is easily recognized and highly characteristic of the Carboniferous (*q.v.*) rocks.

Gas, natural—gaseous hydrocarbon compounds, originating within the earth, probably of organic origin, and usually associated more or less closely with petroleum.

Geanticline—a large, broad, and usually very gentle anticline (*q.v.*), commonly many miles in width. *See* also geosyncline.

Geologist—one who has made a special study of the science of geology. A petroleum geologist is primarily one who has especially investigated the applications of geology to a search for oil and gas, but is expected to have a sufficient general knowledge of the oil and gas business that he can properly estimate not only the chances of success in drilling but also the probable and possible loss and gain. *See* index.

Geology—that science which treats of the origin, history, and structure of the earth, as recorded in the rocks; together with the forces and processes now operating to modify rocks.

Geosyncline—a large, broad, shallow syncline (*q.v.*), commonly many miles in breadth. *See* also geanticline.

Glacial deposits—unstratified, or in some cases roughly stratified masses of sand, gravel, clay, and bowlders which have been transported by glaciers. The only important glacial deposits in the United States are of Pleistocene (*q.v.*) age.

Gradient—inclination, as of a river course, or a rock stratum, usually expressed in degrees, per cent. slope, or feet per mile. A term often used to describe the slope of rock beds.

Gradienter screw—a slow-motion tangent screw controlling the inclination of the telescope. To the head of the screw is fastened a drum usually graduated into 100 divisions. The pitch of the threads is such that one complete revolution of the screw moves the horizontal cross-wire (*q.v.*) through a stadia (*q.v.*) angle, that is, over 1 ft. of the rod at a distance of 100 ft. Thus the screw can be used for determining both horizontal distances and differences in elevation. *See* index.

Granite—a coarse grained, deep seated igneous (*q.v.*) rock of granitoid texture consisting essentially of quartz and orthoclase feldspar, usually with mica or hornblende. Granites do not yield oil or gas in paying quantities.

Gravel—an unconsolidated mixture of rock fragments, bowlders, and pebbles of variable size, but larger than those of sand.

Gravity—*see* Baumé system, also specific gravity.

Gravity fault—a very loosely used and indefinite term, originally meant to apply to faults produced by gravity, *i.e.*, by settling of the beds. Commonly used to designate a fault (*q.v.*) in which the hanging wall (*q.v.*) is the downthrow side. *See* also thrust fault, normal fault, and reversed fault.

Grits—coarse grained and often impure sandstones (*q.v.*).

Gusher—an oil well from which the oil spouts of itself, or flows freely without pumping.

Gypsum or "gyp"—calcium sulphate with water of crystallization ($CaSO_4.2H_2O$). Occurring alone, or with common salt, it is characteristic of sediments laid down in lakes in arid regions. Is also found associated with salt in the domes of the Gulf Coast Region.

Hade—the angle that a plane makes with the vertical. Hade is the complement of the dip (*q.v.*), which may be defined as the angle the plane makes with the horizontal. These angles are measured in a vertical plane, normal to the strike (*q.v.*) of the inclined plane.

Hand level—a small level provided with a sighting tube, which in some types carries a telescope. The arrangement by means of a mirror, is such that the observer can see the object sighted and the level bubble at the same time. When the cross-wire bisects the bubble and the object viewed, that object is on a level with the eye. *See* index.

Hanging wall—that wall of a dipping vein or fault (*q.v.*) that overhangs the fracture. *See* also foot wall.

Heave—the horizontal component of fault movement in a direction normal to the strike of the fault (*q.v.*).

Heavy oil—oil of low gravity Baumé (*q.v.*), from about 30° down; that is, oil with a high specific gravity (*q.v.*).

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"Highs"—high points, either topographically or structurally; hence designated as "topographic highs" and "structural highs." The latter are the crests of anticlines. *See* index.

Hog-backs—sharp ridges caused by unequal erosion on alternating hard and soft layers of steeply inclined rock. Sometimes applied to ridges formed by hard dikes (*q.v.*). A hog-back differs from a cuesta (*q.v.*) in having the rocks more nearly vertical and the two slopes of the ridge more nearly equal.

Homocline—a condition in which the rocks all dip in one direction over considerable areas, although not a true one-limbed flexure; spoken of as a monoclinal dip. *See* monocline.

Horizon—a particular stratigraphic position, as the horizon of a certain fossil, meaning the particular place in the stratigraphic column where that fossil occurs, even though in widely separated localities.

Humidity—the amount of moisture in the air. Relative humidity is the percentage that the moisture in the air is of the total moisture that the air could hold at the given temperature, while absolute humidity is the actual weight of moisture in a given volume of air.

Hydrocarbons—compounds of the elements hydrogen and carbon, in either solid, liquid, or gaseous form. Natural gas and petroleum (*q.v.*) are mixtures of hydrocarbons.

Hydrodynamic pressure—pressure exerted by the deflection of moving water.

Hydrostatic pressure—pressure due to still water.

Igneous rocks—those rocks which have solidified or crystallized from a hot fluid mass called a magma. Igneous rocks, particularly those that have cooled deep in the earth such as granites (*q.v.*), are usually very compact and have an extremely low porosity. They are decidedly unfavorable to oil accumulation. *See* pyroclastic, tuff, intrusive, extrusive, etc.

Impermeable—impervious, not easily permeated, as by oil or water, either because of low porosity, very small individual pores, or pores that are disconnected.

Impervious rocks—rocks that will not allow passage of oil or water.

Initial dip—inclination of beds which is due to being deposited upon an uneven surface and not to folding.

Initial production—the rate of production at which a well first comes in.

Inlier—an area of older rock entirely surrounded in outcrop by younger rock. May be caused by the eroded crest of an anticline (*q.v.*), by erosion on the upthrow side of a fault (*q.v.*), or by partial burial of isolated hills on an old erosion surface. *See* index.

Inspissation—evaporation of the lighter constituents of petroleum, leaving the heavier residue behind, as in the formation of asphalt (*q.v.*) rock.

Instrument man—one who uses a surveying instrument; in oil work, specifically, the one who uses the telescopic alidade as contrasted with the geologist who carries the rod and follows the outcrop. *See* index.

Intercept—that portion of the rod seen between the upper and lower stadia (*q.v.*) wires of a transit or telescopic alidade (*q.v.*), used for determining distance. *See* index.

Interval—the distance between any two given horizons (*q.v.*) as measured in a direction normal to them. (1) Stratigraphic interval, the vertical distance between two strata. This may vary from point to point. *See* convergence, isochore, and iso-pachous lines. (2) Contour interval. *See* contour. *See* index.

Intrusives—igneous rocks (*q.v.*), such as granites (*q.v.*), that have solidified below the surface of the earth. They are usually massive, non-porous, and unsuited to oil accumulations. *See* also extrusives.

Isobath—a structural contour line, a line drawn through points of equal elevation on the surface of a given rock bed. At the outcrop the isobath is at the surface of the ground; where the bed is buried, it is below the surface; and where the bed has been removed by erosion, it is above the surface. Isobaths show the configuration of rock folds. *See* structural contour and contour. *See* index.

Isochore—a line drawn through points of equal interval (*q.v.*) between successive beds. An isochore map is the same as a convergence chart (*q.v.*).

Isocline—a fold, the limbs of which are parallel to each other.

Isogonic chart—a chart showing lines of equal magnetic declination (*q.v.*).

Iso-pachous lines—lines on a map drawn through points of equal thickness of an oil sand.

Johnson movement—a ball and socket joint, combined with a swivel joint, used with plane tables (*q.v.*), to facilitate leveling the planchett (*q.v.*) and turning it after it is level. Invented by W. D. Johnson. *See* index.

Joints—fractures or cracks in the rocks, but without sufficient movement of the walls to be called faults (*q.v.*).

Jurassic—the second period of the Mesozoic (*q.v.*) era. Jurassic rocks in the United States are partly marine (*q.v.*) and partly terrestrial (*q.v.*). Up to date, no important oil production in this country is known from rocks of Jurassic age.

Kerosene shales—*see* oil shales.

Key bed—a term used in two senses. In one sense it applies to any bed of sufficiently distinctive characteristics to serve as an easily identifiable horizon in correlation (*q.v.*). In another sense it applies to the datum horizon (*q.v.*) on which elevations are taken, or to which elevations are finally computed, in making a structural contour map. *See* index.

Laminæ—very thin beds, as of shale. Very thin-bedded rocks are said to be laminated.

Lateral variation—variation parallel to the bedding in the same bed, stratum or formation (*q.v.*); either in character of material, degree of porosity, thickness, or some other feature. Variations in thickness and in porosity are of particular importance in influencing oil accumulation. *See* terrestrial deposits and littoral deposits.

Lava—igneous rock (*q.v.*) that has been poured out upon the surface and there solidified, usually in sheets. *See* extrusive.

Lens—a term used in two senses. (1) a lentil, a sedimentary bed that grows thinner in all directions to complete or practical disappearance; the bed is said to "lens out," or "pinch out;" (2) a piece of glass so shaped as to bring the rays of light to a focus and produce an image as the light passes through. *See* index.

Lenticular—lens-shaped.

Level—an instrument provided with a bubble-tube (*q.v.*), and made use of in determining horizontal, or level lines, usually as a means of determining elevation. *See* index.

Level-vial—the tube that contains the bubble, in any leveling instrument. *See* index.

Light oil—oil with a high gravity Baumé (*q.v.*), ranging from about 30° upward; that is, it has a low specific gravity (*q.v.*); usually a paraffin-base oil.

Limestone—a sedimentary rock (*q.v.*) consisting essentially of the mineral calcite (calcium carbonate). It may be shaly or sandy, depending on the impurities. If it contains much of the double carbonate of lime and magnesia, it is usually termed magnesian limestone, or dolomite. Limestones vary greatly in porosity, some being highly impervious; others are sufficiently porous to constitute good reservoirs for oil accumulation.

Line of collimation—*see* collimation. *See* also index.

Lithologic similarity—similarity of various rock formations with regard to physical properties, such as size of grain, mineral content, color, etc. *See* index.

Lithology—that branch of geology that deals with the origin and properties of rocks.

Littoral deposits—those sediments formed in the shore zone under the influence of active wave work. Characterized by coarseness, ripple marks, cross-bedding (*q.v.*), and extremely rapid lateral variation (*q.v*).

Locke level—a special type of hand level designed by John Locke. Now used rather loosely for almost any simple type of hand level. *See* index.

Log—the detailed record of the rocks passed through in drilling. When accurate, logs constitute a valuable source of information.

Longitudinal valleys—strike valleys (*q.v.*), those cut on softer layers of rock parallel to the upturned edges of harder layers which form ridges. *See* index.

Lows—used in two senses; (1) an area of low barometric (*q.v.*) pressure, a storm center; (2) a region structurally low, as a syncline (*q.v.*); some-

times also applied to saddles between local "highs" (*q.v.*) along the crests of anticlines (*q.v.*).

Mantle rock—the loose, unconsolidated rock material, such as sand, gravel, clay, etc., resting on the solid rock; soil. Frequently termed "surface" in logs.

Marine formations—those formations laid down in the sea as contrasted with those laid down on land or in lakes.

Markers—(1) specially marked points on a rod used to aid in its reading; (2) strata with easily recognized characteristics, such as make simple their identification in the field. *See* index.

Marsh gas—methane (CH_4), the chief constituent of natural gas but often resulting from the partial decay of plants in swamps. Not uncommonly misinterpreted as an indication of the presence of petroleum.

Matrix—the finer particles of sand, clay, or other substances in which the coarser particles of a conglomerate (*q.v.*) are embedded and by which they are cemented.

Member—a subdivision of a formation (*q.v.*) not usually mapped as a separate unit, but sufficiently distinctive to merit separate detailed description. Not uncommonly the members of a large formation are, as a result of more detailed work, raised to the rank of formations.

Mercurial barometer—a barometer (*q.v.*) consisting of a glass tube closed at one end, filled with mercury, and inverted into a dish of mercury. The pressure of the air on the mercury in the dish holds a column of mercury in the tube, and the upper surface of this column rises and falls with variations of atmospheric pressure. *See* also aneroid. *See* index.

Mesozoic era—the era following the Paleozoic (*q.v.*) and preceding the Cenozoic (*q.v.*). The Mesozoic is divided into the Triassic (*q.v.*), Jurassic (*q.v.*), and Cretaceous (*q.v.*) periods.

Metamorphic rocks—rocks which, as a result of heat or pressure, or both, have been partially or wholly altered to new rocks. Common types are slates, schists, marbles, and gneisses. They are usually of very low porosity, and not suited to oil accumulation.

Methane—*see* marsh gas.

Migration—the movement of oil or gas through the pores of the rock. The rate of movement varies with the permeability of the rock, with the viscosity of the oil, and with other factors. Migration is essential to accumulation, but the distance which the oil may travel, and the effect of migration on the oil itself are not well known. *See* index.

Mineral oil—another name for petroleum and its derivatives.

Miocene epoch—the third epoch of the Tertiary (*q.v.*). Miocene is known on the coastal plain, where it is chiefly marine; in the Rocky Mountains and Great Basin, where it consists of terrestrial sediments mingled with volcanic rocks; and on the Pacific Coast, where it consists largely of marine sediments. It is oil bearing in California, and in the Gulf Coast region.

Mississippian epoch—the earliest epoch of the Carboniferous (*q.v.*) period. Rocks of this series are widespread in the United States, where they are chiefly sedimentary and contain a large proportion of limestone. Oil and gas is produced in commercial quantities from rocks of this age.

Mississippi lime—in the Mid-Continent Field, the limestone just below the Pennsylvanian (*q.v.*) series. Some confusion arises by applying it both to the black lime (probably the Mound and Pitken formations) and to the stratigraphically underlying white lime (probably the Boone). It was formerly believed that there was no use drilling into the "Mississippi lime," but it is now certain that there are possibilities in these and lower beds.

Monocline—properly a one-limbed fold with the beds inclined in one direction only; in common usage, however, often applied to dips in only one direction, even though representing but one limb of a very large anticline (*q.v.*) or syncline (*q.v.*). Homocline (*q.v.*) is now being used to some extent for the latter. *See* index.

Monocular hand level—any hand level (*q.v.*) with one sighting tube, applied specifically to a Gurley instrument of the more complex telescopic type. *See* index.

Mounds—in the Gulf Coast Field the topographic elevations, some of which mark the sites of the salt domes; in general, any prominent, more or less isolated hill.

Natural gas—*see* gas, natural.

Nodules—*see* concretions.

Normal fault—a fault (*q.v.*) in which, as referred to a vertical section normal to its strike, the hanging wall appears to have moved down; *i.e.*, the fault plane dips toward the downthrow side.

Nose—a relatively small, pitching (*q.v.*) anticline, without individual closure; a plunging (*q.v.*) anticline.

Objective—the lens or lenses at the opposite end from the eyepiece in a telescope or microscope. *See* index.

Ocular—the lens, or combination of lenses of a microscope or telescope which constitute the eyepiece. *See* index.

Offset well—a well drilled opposite to a well on an adjoining property, the distance between them (usually 600 ft.) being such that it is not expected that a well will be drilled therein.

Oil—the common term for liquid petroleum as found in nature; a mixture of natural liquid hydrocarbons.

Oil field—a general oil-producing region, which may be large or small, and usually consists of numerous individual pools. *See* oil pool.

Oil geologist—*see* geologist.

Oil pool—a division of an oil field (*q.v.*); the contiguous area that produces oil. The entire area of a pool is usually related to a single structural feature, such as an anticline (*q.v.*).

"Oil sand"—any stratum containing oil. Because of the higher average porosity of sandstone, most "oil sands" are true sandstones (*q.v.*), but many are porous limestones (*q.v.*). *See* index.

Oil shale—highly organic shales which are capable of yielding, upon proper retorting, liquid hydrocarbons of the general nature of petroleum.

Oligocene epoch—the second epoch of the Tertiary (*q.v.*) period.

Oolitic—consisting of oolites, or small concretionary particles, cemented together to form a rock mass. Each individual oolite, or tiny concretion, is about the size of a millet seed, and may consist of silica, calcium carbonate, iron oxide, or other substance. Named from the resemblance to fish eggs.

Open pressure—the pressure on a gas well that has been open long enough for the accumulated pressure to waste. *See* also closed pressure.

Open sand—one that is porous and relatively permeable, as contrasted with tight sand, which is relatively impermeable.

Ordovician period—the second period of the Paleozoic (*q.v.*) era; characterized in the United States by widespread limestone formations. The Trenton limestone of this period is the "oil sand" of the Ohio-Indiana Field.

Orientation—the placing of a map or instrument in such a position that its directions coincide with the points of the compass.

Oscillation—applied in part to changes in sea level, bringing about, as a rule, corresponding changes in the character of the sediments being deposited.

Outcrops—specifically, actual exposure of ledge, or bedrock (*q.v.*); in a more general sense, area of outcrop of a formation indicates the area over which the formation directly underlies the surface soil, even though not actually bare and exposed.

Outlier—an area of younger rock entirely surrounded in outcrop by older rock; caused by the younger rock cappings on isolated hills; by planation of synclines (*q.v.*) leaving remnants of younger rock in the center; or by erosion leaving younger remnants on the downthrow side of a fault (*q.v.*). *See* index.

Overthrust—a very low-angle fault (*q.v.*) caused by thrust.

Overturned fold—any fold in which one limb has passed the vertical so that the beds in that limb are no longer right side up.

Paleontology—the study of evidences of the life of the past as preserved in the rocks; more specifically a study of fossils (*q.v.*), especially in their application to problems of correlation (*q.v.*).

Paleozoic era—the era following the Proterozoic (*q.v.*) and preceding the Mesozoic (*q.v.*). It is divided into the Cambrian (*q.v.*), Ordovician (*q.v.*), Silurian (*q.v.*), Devonian (*q.v.*), and Carboniferous (*q.v.*) periods.

Paraffin-base oil—an oil, the chief solid residue of which is paraffin, as contrasted with one which has a base of asphalt.

Paraffin dirt—peculiar "curdy" or "rubbery" soil, of the Gulf Coast region, believed to be formed by the action of escaping gas on peat or humus. It is doubtful whether it contains any true paraffin. It is thought that it may indicate either seeps of natural gas, or of ordinary marsh gas, and its value as an oil indication is in much dispute. *See* index.

Parallax—apparent displacement of an object, due to the position of the observer. For example, in looking through a hand level, the observer, by slightly moving the eye, can shift the apparent line of coincidence of the bubble, the cross-wire, and the object viewed. *See* index.

Pay, pay sand, pay streak—that portion of an oil or gas sand in which the oil or gas is concentrated. *See* oil sand.

Peneplanation—the wearing down of a land surface by erosion (*q.v.*) to a nearly level plain, termed a peneplain. Also spelled peneplane.

Pennsylvanian epoch—the middle epoch of the Carboniferous (*q.v.*) period. Pennsylvanian rocks in the United States are chiefly sedimentary; are important sources of coal in the Appalachian, Illinois, and Western Interior Fields; and carry much oil and gas in the Mid-Continent Field.

Period—a unit of geological time, smaller than an era (*q.v.*) and larger than an epoch (*q.v.*). Cambrian, Carboniferous, Cretaceous, and Tertiary are examples of periods (*q.v.*).

Permeable—easily penetrated by solutions, as by water or oil; usually said of porous rocks, though not all porous rocks are permeable; those in which the pores are not well connected being relatively impermeable.

Permian epoch—the latest epoch of the Carboniferous (*q.v.*) period. Over most of the western United States the Permian consists largely of "red beds" (*q.v.*), probably laid down on land under arid conditions, as a result of which they are deficient in organic matter, and in general, therefore, not promising oil territory. Are thought to produce oil and gas in commercial quantities in some places.

Persistence—the condition of continuity of beds, and regularity in character and thickness. Because of more uniform conditions in the ocean than on land, marine beds (*q.v.*) are more persistent than terrestrial (*g.v.*), and limestones than sandstones laid down nearer shore. *See* lateral variation and littoral deposits.

Pervious rocks—*see* permeable.

Petroleum—a mixture of natural liquid hydrocarbons of very variable composition. Contains compounds ranging from solid to gaseous. *See* gas, asphalt, hydrocarbons.

Petroleum geologist—*see* geologist.

Petroleum seep or spring—a natural outlet where petroleum escapes to the surface of the ground. Frequently marked by asphaltic soils.

"Pinching" out—*see* lens.

Pitch—a term used in two very different senses; (1) the inclination of a fold along its axis (*q.v.*); the plunge of a fold; (2) natural solid or extremely viscous hydrocarbon compounds, derived from evaporation of asphalt-base petroleum.

Planchette—the board, or top, of a plane table.

Plane table—a small board mounted on a tripod by means of a swivel or ball-and-socket joint, and used for mapping purposes. *See* index.

Pleistocene epoch—the first epoch of the Quaternary (*q.v.*) period, the epoch of extensive glaciation in North America.

Pliocene epoch—the latest epoch of the Tertiary (*q.v.*) period.

Plug—the solidified core of igneous rock (*q.v.*) in the throat of an old volcano. Sometimes also applied to nearly round dikes (*q.v.*).

Plunging fold—a fold, the axis (*q.v.*) of which is not horizontal; a fold that has pitch (*q.v.*).

Pool—*see* oil pool.

Pore space—the open space, or voids, between the individual grains of a rock mass. Varies greatly, according to various estimates, that of oil sands ranging between 10 and 25 per cent.

Pre-Cambrian—a general term for all time and for all rocks prior to the Cambrian (*q.v.*). As a rule pre-Cambrian rocks [Archean (*q.v.*) and Algonkian (*q.v.*)] are highly metamorphosed. Not known to contain oil or gas in commercial amounts.

Precise leveling—leveling of the highest order of accuracy obtainable.

Pressure—(1) the pressure exerted by a well, chiefly gas pressure, but in part perhaps a result of head of water. *See* closed pressure and open pressure. (2) Atmospheric pressure, the pressure exerted by the weight of a column of air; measured by a barometer (*q.v.*). *See* index.

Production—a term used in related senses to indicate (1) that phase of the petroleum industry that deals with the extraction of the oil and gas from the ground; (2) the amount of oil produced, viz., daily production, monthly production, flush production (*q.v.*), settled production (*q.v.*), to buy production, and the like.

Production curves—curves plotted for individual wells, for pools, or for fields, showing the rate of production at successive periods of time; made particularly for the purpose of studying the rate of decline (*q.v.*) of wells and pools.

Prospect—to search for oil, either by looking for surface indications, such as seeps (*q.v.*) and anticlines (*q.v.*); or by drilling, or by both methods. A prospect is an area which has been located and suspected to be favorable. Only a small proportion of prospects materialize.

Proterozoic—a term used by the United States Geological Survey for what is herein defined as pre-Cambrian (*q.v.*). Proterozoic is used by many authors as a term equivalent to Algonkian (*q.v.*) as herein defined.

Protractor—a portion of a circle laid off in degrees for use in making angular measurements, an instrument in common use by the draftsman.

Proven territory—territory that has been definitely demonstrated to be productive or non-productive by actual drilling. Commonly used to denote the former.

Pyroclastic—fragmental volcanic rock, such as volcanic ash (*q.v.*), tuff (*q.v.*), and agglomerate (*q.v.*).

Quaquaversal—structurally a dome (*q.v.*), the rocks dipping outward in all directions; an anticline nearly circular in plan.

Quartzite—a sandstone which has been so firmly cemented with silica that the cement is as resistant as the quartz grains. Has low porosity and would not serve as an oil reservoir.

Quaternary—the latest period of geologic time, the time of extensive glaciation in North America. Quaternary deposits are widespread at the surface, but are usually patchy and of slight depth. They include glacial formations and are not petroleum producers. *See* glacial deposits.

Reconnaissance work—the preliminary examination of a region. *See* index.

Recovery—the securing of the oil from the rocks; a term used commonly in considering the proportion of the oil that is extracted.

Recurrent faunas—On fluctuating shore lines, the animal life may move back and forth, with the changes of level. At a given point a certain fauna (*q.v.*) may be flourishing on a limey bottom. Uplift brings the area near land so that sand is laid down and conditions are unfavorable, the fauna migrating into deeper water. Now a deepening of the sea, by sinking, may cause lime bottoms once more, and the given fauna may return. This will result in limestones, separated by a sandstone, both limestones having the same fauna, which is said to be recurrent.

"Red beds"—red sands and shales with thin limestones and much gypsum, widespread over western United States, which range in age from late Pennsylvanian (*q.v.*) to Jurassic (*q.v.*), but are largely Permo-Triassic. *See* Permian, Triassic.

Refraction—the bending of light from its course as it passes from rarer to denser or denser to rarer media. *See* lens.

Regional dip—the general dip over a large region which is usually controlled by its relation to some major uplift. *See* index.

Relative humidity—*see* humidity.

Resection—a method of locating the plane table by sights on known points. *See* index.

Reservoir—a rock sufficiently porous to serve as a place of accumulation of oil or gas.

Residual soil or residuum—the soil accumulated in place as a result of the weathering of the rock below; the less soluble residue from which the more soluble rock materials have been leached out.

Reversals—the change from a dip in one direction to one in the opposite. *See* east dip, regional dip. *See* index.

Reversed fault—a fault (*q.v.*) in which, when referred to a cross section at right angles to the strike, the foot-wall appears to have moved down; *i.e.*, the fault plane dips toward the upthrow side. *See* also normal fault, gravity fault, and thrust fault.

Rock asphalt—rock impregnated with asphalt from the evaporation of natural petroleum. *See* asphalt rock.

Rock pressure—a name applied to the pressure (*q.v.*) shown by oil and gas wells.

Rod—a light board or rod painted to read in convenient divisions, such as feet or meters, and used in leveling and stadia (*q.v.*) observations. *See* level, etc. *See* index.

Rodman—the man who uses or carries a surveying rod. In petroleum geologic work, the geologist, who carries the rod and follows the outcrop, in order that the instrument man may determine the location and elevation of points chosen thereon. *See* index.

Saddles—(1) structurally lower places along the crest of an anticline, between two local "highs" (*q.v.*); (2) topographically lower places along the crest of a main ridge or divide, between two local peaks.

Salines—*see* salt domes.

Salt domes—dome-shaped structures in the Gulf Coast Field, in which the dips are usually steep; and which commonly have a core of salt. *See* index.

Salting—fraudulent introduction or enrichment of values in a prospect, to aid the sale or promotion of same.

Sand—finely divided particles of rock material, usually silicious; the particles coarser than those of clay, and smaller than those of gravel. *See* oil sand.

Sandstone—a sedimentary (*q.v.*) rock resulting from the consolidation of sand. Sandstone usually consists essentially of grains of quartz (silica) with minor impurities such as clay, iron oxide, and lime carbonate.

Sapping—the natural process of undermining cliffs by the wearing back of softer layers.

Scarp—an abbreviated form of the word escarpment, more commonly restricted to cliffs produced by faulting.

Scouting—in the geological sense, synonymous with reconnaissance work. Also employed to designate the obtaining of information concerning areas being drilled by others.

Sealing—rendering tight; (1) the cementing of the pores of an outcropping oil sand by asphaltic residue, so that oil is trapped below. (2) Faults (*q.v.*) are said to be sealed when they are rendered tight by shale or clay walls that close sufficiently to prevent the escape of oil.

Sea wax—bitumenous matter thrown up along sea coasts; probably resulting from partial oxidation of sea weeds. Such wax is sometimes mistaken for an indication of the presence of petroleum. *See* index.

Secondary limestone—limestone deposited by solution in cracks and cavities of other rocks; particularly that accompanying the salt and gypsum of the Gulf Coast salt domes.

Sedimentation—the process of laying down sediments; the deposition of finely divided rock material by wind, water, or glaciers.

Sedimentary rocks—rocks laid down in a more or less finely divided state, as sediment, through the agency of water, wind, or glaciers. Sandstones, limestones, shales, and conglomerates are common examples.

Seeps—points at which water, oil, or gas, emerges from the ground in small quantities. Springs are more localized and have a larger flow. *See* index.

Settled production—the steady production of an oil well after a period of some days or months when the rate of decline (*q.v.*) has become small.

Set-up—instrument station; point at which plane table (*q.v.*) and alidade (*q.v.*) are placed for the taking of observations. *See* index.

Shale—a sedimentary rock (*q.v.*) consisting of more or less consolidated fine muds.

Shale oil—oil resulting from the distillation of organic shales. *See* oil shale.

Shell—(1) any thin layer of a harder rock which breaks the continuity of a softer one. (2) A fossil (*q.v.*) or recent external skeleton.

Shift—that horizontal component of a fault (*q.v.*) movement which lies in a direction parallel to the strike of the fault plane.

Shooting—exploding nitro-glycerine or other high explosive in a hole, to shatter the rock and increase the flow of oil. Same as torpedoing.

Shot—(1) in instrument work, a sight (*q.v.*); (2) in shooting wells (*q.v.*), a charge of explosive.

Side-shots—those sights, taken from any set-up (*q.v.*), which are not used as turning-points (*q.v.*), and are therefore not stations in the traverse. *See* backsight, foresight, etc. *See* index.

Sight—each determination of elevation or distance from the set-up (*q.v.*). *See* also set-up, backsight, foresight, and shot.

Silurian period—the third period of the Paleozoic (*q.v.*) era. In the United States, Silurian rocks consist largely of marine (*q.v.*) sediments with abundant limestones, and have produced oil in Michigan and eastern fields.

Slickensides—striæ on rock surfaces, produced by friction along the walls of a fault (*q.v.*).

Sludge—mud or slime; either natural, as in rivers and bays, or artificial from drill cuttings.

Slump—the settling of beds owing to removal of material underneath. On hillsides, large slabs of rock break off and "slump" down, where they give the false impression of dipping beds.

Sour dirt—a dirt impregnated with sulphates resulting from the escape of SO_2 or H_2S. Because sulphur is often associated with petroleum in the salt domes of the Gulf Coast Field, "sour dirt," also known as "copperas dirt," is by many considered as an indication of oil in that region. *See* index.

Specific gravity—the ratio of the weight of a given substance to the weight of an equal volume of water. Not to be confused with gravity Baumé. *See* Baumé and gravity.

Spherical aberration—*see* aberration.

Spilling flow lines—the lines of least resistance along which oil or gas will escape from a structure when it becomes filled.

Spilling point—that point from which when a dome becomes filled with oil or gas, one or both commence to escape.

"Spotty" formations—formations with rapid lateral variations (*q.v.*); that is, with sudden changes in character, particularly applied to variations in porosity, and hence in productive capacity.

Spring—a point where water or oil emerges from the ground in sufficient quantity to flow away; as contrasted with seep (*q.v.*), from which there is no stream flowing away. *See* index.

Stadia—an instrument and an instrument method for measuring distances. *See* index.

Staggering wells—to arrange wells in rows, such that those in one row are placed opposite spaces in the next row.

Station—any point the location or elevation of which is determined. *See* set-up, sight, turning-point, etc.

Stebbinger attachment—the graduated drum (*q.v.*) used with a gradienter screw (*q.v.*).

Stepping method—a method of determining elevations by using the stadia wires. *See* index.

Stratigraphic correlation—the determination of the equivalency or non-equivalency in age of separated rock outcrops, accomplished by means of fossils (*q.v.*), lithologic similarity (*q.v.*), etc. *See* index.

Stratigraphic throw—the displacement produced by faulting, measured normal to the rock strata.

Stratigraphy—the study of rock strata, the conditions of their deposition, their character, age, distribution, and the like.

Stratum—a layer of rock more or less similar throughout, a lithologic unit. It may consist of one or more beds (*q.v.*), and may constitute a formation (*q.v.*) or a member (*q.v.*), or be only one of several strata in such formation or member.

Stray sands—lenticular sands of local distr bution, often not previously found in other drilling in the vicinity and hence not expected. *See* "oil sand," "spotty," and "lateral variations."

Streaks—long narrow lenses of sand; perhaps old beach lines. A well known example is the so-called "shoe-string" near Paola, Kansas.

Striated—covered with parallel scratches, such as fault slickensides (*q.v.*), or glacial scratches (striations).

Striding level—the small, separately-mounted bubble-tube (*q.v.*) that is used on top of a telescope. When not in use, it is removed and clamped on the basal plate of the instrument. *See* level. *See* index.

Strike—the trace of the d pping plane (a rock bed, fault, or vein) on the horizontal. The strike is at right angles to the direction of dip (*q.v.*).

Strike valleys—valleys parallel to the strike (*q.v.*) of the rocks; as contrasted with dip valleys (*q.v.*), at right angles to the strike. Strike valleys are said to be longitudinal, and dip valleys transverse. *See* index.

Structural contours—contour (*q.v.*) lines which represent the structure or shape of the surface of a given rock bed. *See* isobath. *See* index.

Structural high—the crest of a dome or anticline (*q.v.*).

Structural low—the bottom of a structural trough or syncline (*q.v.*).

Structure—in general the attitude of the rocks and the features which determine that attitude, as stratification, faults, anticlines, synclines, terraces (*qq.v.*), etc. In oil work commonly used synonymously with anticline.

Subsurface work—the study of underground conditions from well records. Includes studies of the thickness, porosity, permeability, and variations of sands; the construction of "sand maps" showing structural contours on the "oil sand;" the correlation of sands; and studies of water conditions. A somewhat new and very promising branch of petroleum geology.

Subterranean storage—(1) accumulation of oil and gas in porous rocks underground; (2) the bringing of gas during the summer months from distant points and storing it in some anticline near the point of winter consumption.

Sulphuretted waters—waters containing hydrogen sulphide (H_2S).

Superposition, law of order of—a general law that states the evident fact that in regions where the rock layers have not been disturbed, the oldest are at the bottom of the series, the youngest at the top.

Surface—*see* mantle rock.

Surveys—for oil work are of two types, reconnaissance (*q.v.*), and detailed (*q.v.*). *See* index.

Symmetrical fold—a fold both limbs of which dip equally but in opposite directions.

Synclinal mountains and valleys—mountains and valleys on the sites of synclines.

Syncline—a trough in the rock beds; a structurally low point toward which the rocks dip; a structural basin. *See* also anticline. *See* index.

Synclinorium—a composite syncline, one in which there are minor crenulations or folds on the limbs of the major syncline.

Tangent screw—a slow-motion screw tangent to an arc or circle. *See* gradienter screw. *See* also index.

Tar—a dark viscous asphaltic residue resulting from partial evaporation or distillation of petroleum or other hydrocarbons of asphaltic base.

Terrace—a structural flattening or bench in a prevailing dip. Not to be confused with topographic benches, which may or may not be present. *See* index.

Terrestrial beds—beds laid down on land, as contrasted with marine beds formed in the ocean. Owing to more varied conditions of formation on land, terrestrial beds are subject to greater lateral variation than are marine beds.

Tertiary period—the first period of the Cenozoic (*q.v.*) era. In the United States, Tertiary rocks are abundant on the Coastal Plain where they are in part marine (*q.v.*), and in part terrestrial (*q.v.*); in the Rocky Mountains, where they are terrestrial and partly volcanic; and on the Pacific Coast, where they are both marine and terrestrial. They carry coal in the Rocky Mountains and Pacific states; and oil in California and the Gulf Coast Field. Much foreign oil is of Tertiary age.

Throw—the vertical component of fault (*q.v.*) movement.

Thrust fault—intended to apply to faults (*q.v.*) caused by thrust, in most of which the hanging wall (*q.v.*) is the upthrow (*q.v.*) side. Also applied indiscriminately to all faults in which the hanging wall is the upthrow side. *See* also gravity fault, normal fault, and reversed fault.

"Tie in"—to close a traverse (*q.v.*) by checking for elevation and location on some known point. *See* bench mark.

Tight sand—a sand the pores of which are so few or so filled with clay or cementing material that oil or water does not pass freely through it. *See* open sand. *See* index.

Topographic highs—hills, usually limited to more or less isolated topographically elevated points. *See* index.

Topography—the general configuration of the land surface; the sum total of the results of erosion and deposition on the physigraphic features of a region.

Torpedoing—*see* shooting.

Transit—a surveying instrument consisting essentially of a telescope free to move horizontally and vertically over circles graduated into degrees and minutes, so that bearings (*q.v.*) and vertical angles (*q.v.*) can be read. *See* also stadia, Beaman stadia arc, gradienter, etc.

Transverse valleys—*see* dip valleys.

Traverse—the survey of a given course, by determining the bearings (*q.v.*) and distances of various points, and plotting to scale. For reasons of accuracy

a traverse should usually close on itself, or on some known point. Directions are taken by compass, transit, or alidade; and distances measured by pacing, buggy wheel, chaining, stadia, or other method.

Trenton lime—a widespread dolomitic limestone of middle Ordovician age. It is an important oil-bearing horizon in the Oh'o-Indiana Fields.

Triangulation—the process of locating points by intersection. *See* index.

Triassic—the first period of the Mesozoic (*q.v.*) era. The rocks of this age in the United States are largely terrestrial. "Red beds" (*q.v.*) are characteristic. They have not yielded commercial quantities of oil and gas in this country.

Trinidad asphalt or pitch—natural asphalt which occurs as a large lake in the Island of Trinidad.

Trough—the lowest part of a syncline (*q.v.*), the axis (*q.v.*), or point, toward which the beds dip inward.

Tuff—cemented volcanic ash (*q.v.*); a pyroclastic (*q.v.*) rock.

Turning-point—a station upon which two instrument determinations are usually made, the first, a foresight (*q.v.*), to determine the position and elevation of the point; the second, a backsight (*q.v.*), to determine the position and elevation of the instrument at a new set-up (*q.v.*). *See* index.

Unconformity—an erosion break in the continuity of sedimentation. Where one formation rests on the eroded surface of a lower one, the two are said to be unconformable and the erosional gap is said to be an unconformity. *See* also angular unconformity and disconformity. *See* index.

Unproved territory—territory that has not been tested by drilling.

Uplift—the raising of land areas; not uncommonly applied locally to structurally raised areas, as the Ozark uplift, the Adirondack uplift.

Upthrow side—that side of a fault (*q.v.*) that appears to have been raised relative to the other side. *See* also downthrow side.

Vernier—an auxiliary scale, used to read the main scale more closely than the regular division marks will allow. *See* index.

Vertical angle—the angle between the horizontal and an inclined line of sight, commonly used to determine elevation. *See* index.

Vertical arc—the arc, on a transit or telescopic alidade, by which the inclination of the telescope tube is read and the vertical angle (*q.v.*) thus determined. *See* ndex.

Vertical deformation—the vertical distance as measured on the surface of any given bed between the crest of an anticline (*q.v.*) and the trough of the adjacent syncline (*q.v.*).

Voids—*see* pore space.

Volcanic ash—the finely divided, fragmental rock material violently blown from volcanoes during explosive eruptions. *See* also pyroclastic and tuff.

Volcanic breccia—cemented, coarse, fragmental volcanic material, as contrasted with the finer tuff (*q.v.*). *See* agglomerate, pyroclastic, etc.

Volcanic domes—domes which have been formed by the bowing up of rocks due to the intrusion of igneous (*q.v.*) masses at depth. Some geologists believe this to be the origin of the Gulf Coast salt domes.

Volcanic neck—*see* plug.

Volcanic plug—*see* plug.

Vuggs—small cavities in the rock, probably caused in many cases by shrinkage resulting from replacement of minerals by others of less volume. Also spelled vughs and vugs.

Water sand—any sand that yields water. An oil sand in one locality may be a water sand in another.

Water table—the upper level of the great body of ground water, or that irregular surface below which the pores of the rock are saturated.

Water well—a well yielding water and no oil irrespective of the purpose for which it was drilled.

Wax—*see* sea wax.

West dip—a dip to the west. Such a dip is the rule in the Mid-Continent Field, where it is often simply called "west," and reversals or east dips, "easts." *See* regional dip.

Wet natural gas—a natural gas high in gasoline content.

Wildcat—in the oil world, a term that does not carry the odium that attaches to it in metal mining. Any well is a wildcat, no matter how good the prospects, if in strictly unproved territory. Used to designate various degrees of uncertainty.

APPENDIX

′	sin	tan	cot	cos	
0	.00000	.00000	∞	1.0000	60
1	029	029	3437.7	000	59
2	058	058	1718.9	000	58
3	087	087	1145.9	000	57
4	116	116	859.44	000	56
5	.00145	.00145	687.55	1.0000	55
6	175	175	572.96	000	54
7	204	204	491.11	000	53
8	233	233	429.72	000	52
9	262	262	381.97	000	51
10	.00291	.00291	343.77	1.0000	50
11	320	320	312.52	.99999	49
12	349	349	286.48	999	48
13	378	378	264.44	999	47
14	407	407	245.55	999	46
15	.00436	.00436	229.18	.99999	45
16	465	465	214.86	999	44
17	495	495	202.22	999	43
18	524	524	190.98	999	42
19	553	553	180.93	998	41
20	.00582	.00582	171.89	.99998	40
21	611	611	163.70	998	39
22	640	640	156.26	998	38
23	669	669	149.47	998	37
24	698	698	143.24	998	36
25	.00727	.00727	137.51	.99997	35
26	756	756	132.22	997	34
27	785	785	127.32	997	33
28	814	815	122.77	997	32
29	844	844	118.54	996	31
30	.00873	.00873	114.59	.99996	30
31	902	902	110.89	996	29
32	931	931	107.43	996	28
33	960	960	104.17	995	27
34	.00989	.00989	101.11	995	26
35	.01018	.01018	98.218	.99995	25
36	047	047	95.489	995	24
37	076	076	92.908	994	23
38	105	105	90.463	994	22
39	134	135	88.144	994	21
40	.01164	.01164	85.940	.99993	20
41	193	193	83.844	993	19
42	222	222	81.847	993	18
43	251	251	79.943	992	17
44	280	280	78.126	992	16
45	.01309	.01309	76.390	.99991	15
46	338	338	74.729	991	14
47	367	367	73.139	991	13
48	396	396	71.615	990	12
49	425	425	70.153	990	11
50	.01454	.01455	68.750	.99989	10
51	483	484	67.402	989	9
52	513	513	66.105	989	8
53	542	542	64.858	988	7
54	571	571	63.657	988	6
55	.01600	.01600	62.499	.99987	5
56	629	629	61.383	987	4
57	658	658	60.306	986	3
58	687	687	59.266	986	2
59	716	716	58.261	985	1
60	.01745	.01746	57.290	.99985	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	01745	01746	57.290	99985	60
1	774	775	56.351	984	59
2	803	804	55.442	984	58
3	832	833	54.561	983	57
4	862	862	53.709	983	56
5	.01891	.01891	52.882	.99982	55
6	920	920	52.081	982	54
7	949	949	51.303	981	53
8	.01978	.01978	50.549	980	52
9	.02007	.02007	49.816	980	51
10	.02036	.02036	49.104	.99979	50
11	065	066	48.412	979	49
12	094	095	47.740	978	48
13	123	124	47.085	977	47
14	152	153	46.449	977	46
15	.02181	.02182	45.829	.99976	45
16	211	211	45.226	976	44
17	240	240	44.639	975	43
18	269	269	44.066	974	42
19	298	298	43.508	974	41
20	.02327	.02328	42.964	.99973	40
21	356	357	42.433	972	39
22	385	386	41.916	972	38
23	414	415	41.411	971	37
24	443	444	40.917	970	36
25	.02472	.02473	40.436	.99969	35
26	501	502	39.965	969	34
27	530	531	39.506	968	33
28	560	560	39.057	967	32
29	589	589	38.618	966	31
30	.02618	.02619	38.188	.99966	30
31	647	648	37.769	965	29
32	676	677	37.358	964	28
33	705	706	36.956	963	27
34	734	735	36.563	963	26
35	.02763	.02764	36.178	.99962	25
36	792	793	35.801	961	24
37	821	822	35.431	960	23
38	850	851	35.070	959	22
39	879	881	34.715	959	21
40	.02908	.02910	34.368	.99958	20
41	938	939	34.027	957	19
42	967	968	33.694	956	18
43	.02996	.02997	33.366	955	17
44	.03025	.03026	33.045	954	16
45	.03054	.03055	32.730	.99953	15
46	083	084	32.421	952	14
47	112	114	32.118	952	13
48	141	143	31.821	951	12
49	170	172	31.528	950	11
50	.03199	.03201	31.242	.99949	10
51	228	230	30.960	948	9
52	257	259	30.683	947	8
53	286	288	30.412	946	7
54	316	317	30.145	945	6
55	.03345	.03346	29.882	.99944	5
56	374	376	29.624	943	4
57	403	405	29.371	942	3
58	432	434	29.122	941	2
59	461	463	28.877	940	1
60	.03490	.03492	28.636	.99939	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.03490	.03492	28.636	99939	60
1	519	521	.399	938	59
2	548	550	28.166	937	58
3	577	579	27.937	936	57
4	606	609	.712	935	56
5	.03635	03638	27.490	.99934	55
6	664	667	.271	933	54
7	693	696	27.057	932	53
8	723	725	26.845	931	52
9	752	754	637	930	51
10	.03781	.03783	26 432	.99929	50
11	810	812	230	927	49
12	839	842	26.031	926	48
13	868	871	25.835	925	47
14	897	900	642	924	46
15	.03926	.03929	25 452	.99923	45
16	955	958	264	922	44
17	.03984	.03987	25.080	921	43
18	.04013	.04016	24 898	919	42
19	042	046	719	918	41
20	.04071	.04075	24 542	.99917	40
21	100	104	368	916	39
22	129	133	.196	915	38
23	159	162	24.026	913	37
24	188	191	23.859	912	36
25	.04217	04220	23.695	.99911	35
26	246	250	532	910	34
27	275	279	.372	909	33
28	304	308	.214	907	32
29	333	337	23.058	906	31
30	.04362	.04366	22.904	.99905	30
31	391	395	752	904	29
32	420	424	.602	902	28
33	449	454	454	901	27
34	478	483	.308	900	26
35	.04507	04512	22.164	.99898	25
36	536	541	22.022	897	24
37	565	570	21.881	896	23
38	594	599	.743	894	22
39	623	628	.606	893	21
40	.04653	.04658	21.470	.99892	20
41	682	687	337	890	19
42	711	716	.205	889	18
43	740	745	21.075	888	17
44	769	774	20.946	886	16
45	.04798	.04803	20.819	.99885	15
46	827	833	.693	883	14
47	856	862	.569	882	13
48	885	891	.446	881	12
49	914	920	.325	879	11
50	.04943	.04949	20.206	.99878	10
51	.04972	.04978	20.087	876	9
52	.05001	.05007	19.970	875	8
53	030	037	.855	873	7
54	059	066	.740	872	6
55	.05088	.05095	19.627	.99870	5
56	117	124	.516	869	4
57	146	153	.405	867	3
58	175	182	.296	866	2
59	205	212	.188	864	1
60	.05234	.05241	19.081	.99863	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.05234	.05241	19.081	.99863	60
1	263	270	18.976	861	59
2	292	299	871	860	58
3	321	328	768	858	57
4	350	357	.666	857	56
5	.05379	.05387	18.564	.99855	55
6	408	416	.464	854	54
7	437	445	366	852	53
8	466	474	268	851	52
9	495	503	171	849	51
10	.05524	05533	18 075	.99847	50
11	553	562	17 980	846	49
12	582	591	886	844	48
13	611	620	793	842	47
14	640	649	.702	841	46
15	.05669	05678	17 611	.99839	45
16	698	708	521	838	44
17	727	737	431	836	43
18	756	766	343	834	42
19	785	795	.256	833	41
20	.05814	.05824	17 169	.99831	40
21	844	854	17.084	829	39
22	873	883	16.999	827	38
23	902	912	915	826	37
24	931	941	.832	824	36
25	.05960	.05970	16.750	.99822	35
26	.05989	.05999	.668	821	34
27	.06018	.06029	.587	819	33
28	047	058	.507	817	32
29	076	087	.428	815	31
30	.06105	.06116	16.350	.99813	30
31	134	145	.272	812	29
32	163	175	195	810	28
33	192	204	119	808	27
34	221	233	16.043	806	26
35	.06250	.06262	15.969	.99804	25
36	279	291	.895	803	24
37	308	321	.821	801	23
38	337	350	.748	799	22
39	366	379	.676	797	21
40	.06395	.06408	15.605	.99795	20
41	424	438	.534	793	19
42	453	467	.464	792	18
43	482	496	.394	790	17
44	511	525	.325	788	16
45	.06540	.06554	15.257	.99786	15
46	569	584	.189	784	14
47	598	613	.122	782	13
48	627	642	15.056	780	12
49	656	671	14.990	778	11
50	.06685	.06700	14.924	.99776	10
51	714	730	.860	774	9
52	743	759	.795	772	8
53	773	788	.732	770	7
54	802	817	.669	768	6
55	.06831	.06847	14.606	.99766	5
56	860	876	544	764	4
57	889	905	.482	762	3
58	918	934	.421	760	2
59	947	963	.361	758	1
60	.06976	.06993	14.301	.99756	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.06976	.06993	14.301	99756	60
1	.07005	.07022	.241	754	59
2	034	051	.182	752	58
3	063	080	.124	750	57
4	092	110	.065	748	56
5	.07121	.07139	14.008	.99746	55
6	150	168	13.951	744	54
7	179	197	.894	742	53
8	208	227	838	740	52
9	237	256	.782	738	51
10	.07266	.07285	13.727	.99736	50
11	295	314	672	734	49
12	324	344	.617	731	48
13	353	373	.563	729	47
14	382	402	.510	727	46
15	07411	.07431	13.457	.99725	45
16	440	461	404	723	44
17	469	490	.352	721	43
18	498	519	.300	719	42
19	527	548	.248	716	41
20	.07556	07578	13.197	.99714	40
21	585	607	.146	712	39
22	614	636	.096	710	38
23	643	665	13.046	708	37
24	672	695	12.996	705	36
25	.07701	.07724	12.947	.99703	35
26	730	753	.898	701	34
27	759	782	.850	699	33
28	788	812	.801	696	32
29	817	841	.754	694	31
30	.07846	.07870	12.706	.99692	30
31	875	899	.659	689	29
32	904	929	.612	687	28
33	933	958	.566	685	27
34	962	.07987	.520	683	26
35	.07991	.08017	12.474	.99680	25
36	.08020	046	.429	678	24
37	049	075	.384	676	23
38	078	104	.339	673	22
39	107	134	.295	671	21
40	.08136	.08163	12.251	.99668	20
41	165	192	.207	666	19
42	194	221	.163	664	18
43	223	251	.120	661	17
44	252	280	.077	659	16
45	.08281	.08309	12.035	.99657	15
46	310	339	11.992	654	14
47	339	368	.950	652	13
48	368	397	.909	649	12
49	397	427	.867	647	11
50	.08426	.08456	11.826	.99644	10
51	455	485	.785	642	9
52	484	514	.745	639	8
53	513	544	.705	637	7
54	542	573	.664	635	6
55	.08571	.08602	11 625	.99632	5
56	600	632	.585	630	4
57	629	661	.546	627	3
58	658	690	.507	625	2
59	687	720	.468	622	1
60	.08716	.08749	11.430	.99619	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	08716	08749	11 430	99619	60
1	745	778	.392	617	59
2	774	807	.354	614	58
3	803	837	.316	612	57
4	831	866	279	609	56
5	08860	08895	11 242	.99607	55
6	889	925	.205	604	54
7	918	954	.168	602	53
8	947	08983	.132	599	52
9	.08976	.09013	095	596	51
10	.09005	09042	11.059	99594	50
11	034	071	11.024	591	49
12	063	101	10.988	588	48
13	092	130	.953	586	47
14	121	159	.918	583	46
15	09150	09189	10.883	.99580	45
16	179	218	.848	578	44
17	208	247	.814	575	43
18	237	277	.780	572	42
19	266	306	.746	570	41
20	09295	.09335	10.712	.99567	40
21	324	365	.678	564	39
22	353	394	.645	562	38
23	382	423	.612	559	37
24	411	453	.579	556	36
25	.09440	.09482	10.546	99553	35
26	469	511	.514	551	34
27	498	541	.481	548	33
28	527	570	449	545	32
29	556	600	.417	542	31
30	.09585	09629	10.385	99540	30
31	614	658	.354	537	29
32	642	688	.322	534	28
33	671	717	.291	531	27
34	700	746	.260	528	26
35	09729	09776	10.229	.99526	25
36	758	805	.199	523	24
37	787	834	.168	520	23
38	816	864	.138	517	22
39	845	893	.108	514	21
40	09874	.09923	10.078	.99511	20
41	903	952	.048	508	19
42	932	.09981	10.019	506	18
43	961	.10011	9.9893	503	17
44	.09990	040	.9601	500	16
45	.10019	.10069	9.9310	.99497	15
46	048	099	.9021	494	14
47	077	128	.8734	491	13
48	106	158	8448	488	12
49	135	187	.8164	485	11
50	10164	.10216	9 7882	.99482	10
51	192	246	.7601	479	9
52	221	275	.7322	476	8
53	250	305	.7044	473	7
54	279	334	.6768	470	6
55	.10308	.10363	9.6493	.99467	5
56	337	393	.6220	464	4
57	366	422	.5949	461	3
58	395	452	.5679	458	2
59	424	481	.5411	455	1
60	.10453	.10510	9.5144	.99452	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.10453	.10510	9.5144	.99452	60
1	482	540	.4878	449	59
2	511	569	.4614	446	58
3	540	599	.4352	443	57
4	569	628	.4090	440	56
5	.10597	.10657	9.3831	.99437	55
6	626	687	.3572	434	54
7	655	716	.3315	431	53
8	684	746	.3060	428	52
9	713	775	.2806	424	51
10	.10742	.10805	9.2553	.99421	50
11	771	834	.2302	418	49
12	800	863	.2052	415	48
13	829	893	.1803	412	47
14	858	922	.1555	409	46
15	.10887	.10952	9.1309	.99406	45
16	916	.10981	.1065	402	44
17	945	.11011	.0821	399	43
18	.10973	040	.0579	396	42
19	.11002	070	.0338	393	41
20	.11031	.11099	9.0098	.99390	40
21	060	128	8.9860	386	39
22	089	158	.9623	383	38
23	118	187	.9387	380	37
24	147	217	.9152	377	36
25	.11176	.11246	8.8919	.99374	35
26	205	276	.8686	370	34
27	234	305	.8455	367	33
28	263	335	.8225	364	32
29	291	364	.7996	360	31
30	.11320	.11394	8.7769	.99357	30
31	349	423	.7542	354	29
32	378	452	.7317	351	28
33	407	482	.7093	347	27
34	436	511	.6870	344	26
35	.11465	.11541	8.6648	.99341	25
36	494	570	.6427	337	24
37	523	600	.6208	334	23
38	552	629	.5989	331	22
39	580	659	.5772	327	21
40	.11609	.11688	8.5555	.99324	20
41	638	718	.5340	320	19
42	667	747	.5126	317	18
43	696	777	.4913	314	17
44	725	806	.4701	310	16
45	.11754	.11836	8.4490	.99307	15
46	783	865	.4280	303	14
47	812	895	.4071	300	13
48	840	924	.3863	297	12
49	869	954	.3656	293	11
50	.11898	.11983	8.3450	.99290	10
51	927	.12013	.3245	286	9
52	956	042	.3041	283	8
53	.11985	072	.2838	279	7
54	.12014	101	.2636	276	6
55	.12043	.12131	8.2434	.99272	5
56	071	160	.2234	269	4
57	100	190	.2035	265	3
58	129	219	.1837	262	2
59	158	249	.1640	258	1
60	.12187	.12278	8.1443	.99255	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.12187	.12278	8.1443	.99255	60
1	216	308	.1248	251	59
2	245	338	.1054	248	58
3	274	367	.0860	244	57
4	302	397	.0667	240	56
5	.12331	.12426	8.0476	.99237	55
6	360	456	.0285	233	54
7	389	485	8.0095	230	53
8	418	515	7.9906	226	52
9	447	544	.9718	222	51
10	.12476	.12574	7.9530	.99219	50
11	504	603	.9344	215	49
12	533	633	.9158	211	48
13	562	662	.8973	208	47
14	591	692	.8789	204	46
15	.12620	.12722	7.8606	.99200	45
16	649	751	8424	197	44
17	678	781	.8243	193	43
18	706	810	.8062	189	42
19	735	840	.7882	186	41
20	.12764	.12869	7.7704	.99182	40
21	793	899	.7525	178	39
22	822	929	.7348	175	38
23	851	958	.7171	171	37
24	880	.12988	.6996	167	36
25	.12908	.13017	7.6821	.99163	35
26	937	047	.6647	160	34
27	966	076	.6473	156	33
28	.12995	106	.6301	152	32
29	.13024	136	.6129	148	31
30	.13053	.13165	7.5958	.99144	30
31	081	195	.5787	141	29
32	110	224	.5618	137	28
33	139	254	.5449	133	27
34	168	284	.5281	129	26
35	.13197	.13313	7 5113	99125	25
36	226	343	4947	122	24
37	254	372	.4781	118	23
38	283	402	.4615	114	22
39	312	432	.4451	110	21
40	13341	13461	7 4287	.99106	20
41	370	491	4124	102	19
42	399	521	3962	098	18
43	427	550	3800	094	17
44	456	580	.3639	091	16
45	.13485	13609	7 3479	99087	15
46	514	639	3319	083	14
47	543	669	3160	079	13
48	572	698	.3002	075	12
49	600	728	.2844	071	11
50	.13629	.13758	7 2687	99067	10
51	658	787	2531	063	9
52	687	817	2375	059	8
53	716	846	2220	055	7
54	744	876	.2066	051	6
55	.13773	.13906	7.1912	.99047	5
56	802	935	1759	043	4
57	831	965	.1607	039	3
58	860	.13995	.1455	035	2
59	889	.14024	.1304	031	1
60	.13917	.14054	7.1154	.99027	0
	cos	cot	tan	sin	′

98° 188° 278° **8°**

′	sin	tan	cot	cos	
0	.13917	.14054	7.1154	.99027	60
1	946	084	.1004	023	59
2	.13975	113	.0855	019	58
3	.14004	143	.0706	015	57
4	033	173	.0558	011	56
5	.14061	.14202	7.0410	.99006	55
6	.090	232	.0264	.99002	54
7	119	262	7.0117	.98998	53
8	148	291	6.9972	994	52
9	177	321	.9827	990	51
10	.14205	.14351	6.9682	.98986	50
11	234	381	.9538	982	49
12	263	410	.9395	978	48
13	292	440	.9252	973	47
14	320	470	.9110	969	46
15	.14349	.14499	6.8969	.98965	45
16	378	529	.8828	961	44
17	407	559	.8687	957	43
18	436	588	.8548	953	42
19	464	618	.8408	948	41
20	.14493	.14648	6.8269	.98944	40
21	522	678	.8131	940	39
22	551	707	.7994	936	38
23	580	737	.7856	931	37
24	608	767	.7720	927	36
25	.14637	.14796	6.7584	.98923	35
26	666	826	.7448	919	34
27	695	856	.7313	914	33
28	723	886	.7179	910	32
29	752	915	.7045	906	31
30	.14781	.14945	6.6912	.98902	30
31	810	.14975	.6779	897	29
32	838	.15005	.6646	893	28
33	867	034	.6514	889	27
34	896	064	.6383	884	26
35	.14925	.15094	6.6252	.98880	25
36	954	124	.6122	876	24
37	.14982	153	.5992	871	23
38	.15011	183	.5863	867	22
39	040	213	.5734	863	21
40	.15069	15243	6.5606	.98858	20
41	097	272	.5478	854	19
42	126	302	.5350	849	18
43	155	332	.5223	845	17
44	184	362	5097	841	16
45	.15212	15391	6.4971	.98836	15
46	241	421	4846	832	14
47	270	451	4721	827	13
48	299	481	.4596	823	12
49	327	511	4472	818	11
50	.15356	.15540	6.4348	.98814	10
51	385	570	.4225	809	9
52	414	600	4103	805	8
53	442	630	.3980	800	7
54	471	660	.3859	796	6
55	.15500	15689	6.3737	.98791	5
56	529	719	.3617	787	4
57	557	749	.3496	782	3
58	586	779	.3376	778	2
59	615	809	.3257	773	1
60	.15643	.15838	6.3138	.98769	0
	cos	cot	tan	sin	′

171° 261° 351° **81°**

9° 99° 189° 279°

′	sin	tan	cot	cos	
0	15643	15838	6.3138	.98769	60
1	672	868	.3019	764	59
2	701	898	.2901	760	58
3	730	928	.2783	755	57
4	758	958	.2666	751	56
5	.15787	.15988	6.2549	.98746	55
6	816	.16017	.2432	741	54
7	845	047	.2316	737	53
8	873	077	.2200	732	52
9	902	107	.2085	728	51
10	.15931	.16137	6.1970	.98723	50
11	959	167	1856	718	49
12	.15988	196	1742	714	48
13	.16017	226	.1628	709	47
14	046	256	1515	704	46
15	.16074	.16286	6.1402	.98700	45
16	103	316	.1290	695	44
17	132	346	1178	690	43
18	160	376	.1066	686	42
19	189	405	.0955	681	41
20	.16218	.16435	6.0844	.98676	40
21	246	465	.0734	671	39
22	275	495	.0624	667	38
23	304	525	.0514	662	37
24	333	555	.0405	657	36
25	16361	16585	6.0296	98652	35
26	390	615	.0188	648	34
27	419	645	6.0080	643	33
28	447	674	5.9972	638	32
29	476	704	.9865	633	31
30	.16505	.16734	5.9758	.98629	30
31	533	764	.9651	624	29
32	562	794	.9545	619	28
33	591	824	.9439	614	27
34	620	854	.9333	609	26
35	.16648	.16884	5.9228	.98604	25
36	677	914	.9124	600	24
37	706	944	9019	595	23
38	734	.16974	8915	590	22
39	763	.17004	.8811	585	21
40	16792	.17033	5.8708	.98580	20
41	820	063	.8605	575	19
42	849	093	.8502	570	18
43	878	123	.8400	565	17
44	906	153	.8298	561	16
45	16935	.17183	5.8197	98556	15
46	964	213	.8095	551	14
47	16992	243	.7994	546	13
48	.17021	273	.7894	541	12
49	050	303	.7794	536	11
50	17078	17333	5 7694	98531	10
51	107	363	7594	526	9
52	136	393	7495	521	8
53	164	423	7396	516	7
54	193	453	.7297	511	6
55	17222	.17483	5.7199	.98506	5
56	250	513	7101	501	4
57	279	543	7004	496	3
58	308	573	6906	491	2
59	336	603	6809	486	1
60	.17365	.17633	5.6713	98481	0
	cos	cot	tan	sin	′

80° 170° 260° 350°

′	sin	tan	cot	cos	
0	.17365	.17633	5.6713	.98481	60
1	393	663	.6617	476	59
2	422	693	.6521	471	58
3	451	723	.6425	466	57
4	479	753	.6329	461	56
5	.17508	.17783	5.6234	.98455	55
6	537	813	.6140	450	54
7	565	843	.6045	445	53
8	594	873	.5951	440	52
9	623	903	.5857	435	51
10	.17651	.17933	5.5764	.98430	50
11	680	963	.5671	425	49
12	708	.17993	.5578	420	48
13	737	.18023	.5485	414	47
14	766	053	.5393	409	46
15	.17794	.18083	5.5301	.98404	45
16	823	113	.5209	399	44
17	852	143	.5118	394	43
18	880	173	.5026	389	42
19	909	203	.4936	383	41
20	.17937	.18233	5.4845	.98378	40
21	966	263	.4755	373	39
22	.17995	293	.4665	368	38
23	.18023	323	.4575	362	37
24	052	353	.4486	357	36
25	.18081	.18384	5.4397	.98352	35
26	109	414	.4308	347	34
27	138	444	.4219	341	33
28	166	474	.4131	336	32
29	195	504	.4043	331	31
30	.18224	.18534	5.3955	.98325	30
31	252	564	.3868	320	29
32	281	594	.3781	315	28
33	309	624	.3694	310	27
34	338	654	.3607	304	26
35	.18367	.18684	5.3521	.98299	25
36	395	714	.3435	294	24
37	424	745	.3349	288	23
38	452	775	.3263	283	22
39	481	805	.3178	277	21
40	.18509	.18835	5.3093	.98272	20
41	538	865	.3008	267	19
42	567	895	.2924	261	18
43	595	925	.2839	256	17
44	624	955	.2755	250	16
45	.18652	.18986	5.2672	.98245	15
46	681	.19016	.2588	240	14
47	710	. 046	.2505	234	13
48	738	076	.2422	229	12
49	767	106	.2339	223	11
50	.18795	.19136	5.2257	.98218	10
51	824	166	.2174	212	9
52	852	197	.2092	207	8
53	881	227	.2011	201	7
54	910	257	.1929	196	6
55	.18938	19287	5.1848	.98190	5
56	967	317	.1767	185	4
57	.18995	347	.1686	179	3
58	.19024	378	.1606	174	2
59	052	408	.1526	168	1
60	.19081	.19438	5.1446	.98163	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.19081	.19438	5.1446	.98163	60
1	109	468	.1366	157	59
2	138	498	.1286	152	58
3	167	529	.1207	146	57
4	195	559	.1128	140	56
5	.19224	.19589	5.1049	.98135	55
6	252	619	.0970	129	54
7	281	649	.0892	124	53
8	309	680	.0814	118	52
9	338	710	.0736	112	51
10	.19366	.19740	5.0658	.98107	50
11	395	770	0581	101	49
12	423	801	.0504	096	48
13	452	831	.0427	090	47
14	481	861	.0350	084	46
15	.19509	.19891	5.0273	.98079	45
16	538	921	.0197	073	44
17	566	952	.0121	067	43
18	595	.19982	5.0045	061	42
19	623	.20012	4.9969	056	41
20	.19652	.20042	4.9894	.98050	40
21	680	073	.9819	044	39
22	709	103	.9744	039	38
23	737	133	.9669	033	37
24	766	164	.9594	027	36
25	.19794	.20194	4.9520	.98021	35
26	823	224	.9446	016	34
27	851	254	.9372	010	33
28	880	285	.9298	.98004	32
29	908	315	.9225	.97998	31
30	.19937	.20345	4.9152	.97992	30
31	965	376	.9078	987	29
32	.19994	406	.9006	981	28
33	.20022	436	.8933	975	27
34	051	466	.8860	969	26
35	.20079	.20497	4.8788	.97963	25
36	108	527	.8716	958	24
37	136	557	.8644	952	23
38	165	588	.8573	946	22
39	193	618	.8501	940	21
40	.20222	.20648	4.8430	.97934	20
41	250	679	.8359	928	19
42	279	709	.8288	922	18
43	307	739	.8218	916	17
44	336	770	.8147	910	16
45	.20364	.20800	4.8077	.97905	15
46	393	830	.8007	899	14
47	421	861	.7937	893	13
48	450	891	.7867	887	12
49	478	921	.7798	881	11
50	20507	.20952	4.7729	.97875	10
51	535	.20982	.7659	869	9
52	563	.21013	.7591	863	8
53	592	043	.7522	857	7
54	620	073	.7453	851	6
55	.20649	21104	4.7385	.97845	5
56	677	134	.7317	839	4
57	706	164	.7249	833	3
58	734	195	.7181	827	2
59	763	225	.7114	821	1
60	.20791	.21256	4.7046	.97815	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.20791	.21256	4.7046	.97815	60
1	820	286	.6979	809	59
2	848	316	.6912	803	58
3	877	347	.6845	797	57
4	905	377	.6779	791	56
5	.20933	.21408	4.6712	.97784	55
6	962	438	.6646	778	54
7	.20990	469	.6580	772	53
8	.21019	499	.6514	766	52
9	047	529	.6448	760	51
10	.21076	.21560	4.6382	.97754	50
11	104	590	.6317	748	49
12	132	621	.6252	742	48
13	161	651	.6187	735	47
14	189	682	.6122	729	46
15	.21218	.21712	4.6057	.97723	45
16	246	743	.5993	717	44
17	275	773	.5928	711	43
18	303	804	.5864	705	42
19	331	834	.5800	698	41
20	.21360	.21864	4.5736	.97692	40
21	388	895	.5673	686	39
22	417	925	.5609	680	38
23	445	956	.5546	673	37
24	474	.21986	.5483	667	36
25	.21502	.22017	4.5420	.97661	35
26	530	047	.5357	655	34
27	559	078	.5294	648	33
28	587	108	.5232	642	32
29	616	139	.5169	636	31
30	.21644	.22169	4.5107	.97630	30
31	672	200	.5045	623	29
32	701	231	.4983	617	28
33	729	261	.4922	611	27
34	758	292	.4860	604	26
35	.21786	.22322	4.4799	.97598	25
36	814	353	.4737	592	24
37	843	383	.4676	585	23
38	871	414	.4615	579	22
39	899	444	.4555	573	21
40	.21928	.22475	4.4494	.97566	20
41	956	505	.4434	560	19
42	.21985	536	.4373	553	18
43	.22013	567	.4313	547	17
44	041	597	.4253	541	16
45	.22070	.22628	4.4194	.97534	15
46	098	658	.4134	528	14
47	126	689	.4075	521	13
48	155	719	.4015	515	12
49	183	750	.3956	508	11
50	.22212	.22781	4.3897	.97502	10
51	240	811	.3838	496	9
52	268	842	.3779	489	8
53	297	872	.3721	483	7
54	325	903	.3662	476	6
55	.22353	.22934	4.3604	.97470	5
56	382	964	.3546	463	4
57	410	.22995	.3488	457	3
58	438	.23026	.3430	450	2
59	467	056	.3372	444	1
60	.22495	.23087	4.3315	.97437	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.22495	.23087	4.3315	.97437	60
1	523	117	.3257	430	59
2	552	148	.3200	424	58
3	580	179	.3143	417	57
4	608	209	.3086	411	56
5	.22637	.23240	4.3029	.97404	55
6	665	271	.2972	398	54
7	693	301	.2916	391	53
8	722	332	.2859	384	52
9	750	363	.2803	378	51
10	.22778	.23393	4.2747	.97371	50
11	807	424	.2691	365	49
12	835	455	.2635	358	48
13	863	485	.2580	351	47
14	892	516	.2524	345	46
15	.22920	.23547	4.2468	.97338	45
16	948	578	.2413	331	44
17	.22977	608	.2358	325	43
18	.23005	639	.2303	318	42
19	033	670	.2248	311	41
20	.23062	.23700	4.2193	.97304	40
21	090	731	.2139	298	39
22	118	762	2084	291	38
23	146	793	.2030	284	37
24	175	823	1976	278	36
25	.23203	.23854	4.1922	.97271	35
26	231	885	.1868	264	34
27	260	916	.1814	257	33
28	288	946	.1760	251	32
29	316	.23977	.1706	244	31
30	.23345	.24008	4.1653	.97237	30
31	373	039	1600	230	29
32	401	069	1547	223	28
33	429	100	.1493	217	27
34	458	131	1441	210	26
35	.23486	.24162	4.1388	.97203	25
36	514	193	1335	196	24
37	542	223	1282	189	23
38	571	254	.1230	182	22
39	599	285	1178	176	21
40	.23627	.24316	4 1126	.97169	20
41	656	347	.1074	162	19
42	684	377	1022	155	18
43	712	408	.0970	148	17
44	740	439	.0918	141	16
45	.23769	.24470	4.0867	.97134	15
46	797	501	.0815	127	14
47	825	532	.0764	120	13
48	853	562	0713	113	12
49	882	593	.0662	106	11
50	.23910	.24624	4.0611	.97100	10
51	938	655	.0560	093	9
52	966	686	.0509	086	8
53	.23995	717	0459	079	7
54	.24023	747	.0408	072	6
55	.24051	24778	4.0358	.97065	5
56	079	809	.0308	058	4
57	108	840	.0257	051	3
58	136	871	.0207	044	2
59	164	902	.0158	037	1
60	.24192	.24933	4.0108	.97030	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.24192	.24933	4.0108	.97030	60
1	220	964	.0058	023	59
2	249	.24995	4.0009	015	58
3	277	.25026	3.9959	008	57
4	305	056	.9910	.97001	56
5	.24333	.25087	3.9861	.96994	55
6	362	118	.9812	987	54
7	390	149	.9763	980	53
8	418	180	.9714	973	52
9	446	211	.9665	966	51
10	.24474	.25242	3.9617	.96959	50
11	503	273	.9568	952	49
12	531	304	.9520	945	48
13	559	335	.9471	937	47
14	587	366	.9423	930	46
15	.24615	.25397	3.9375	.96923	45
16	644	428	.9327	916	44
17	672	459	.9279	909	43
18	700	490	.9232	902	42
19	728	521	.9184	894	41
20	.24756	.25552	3.9136	.96887	40
21	784	583	.9089	880	39
22	813	614	.9042	873	38
23	841	645	.8995	866	37
24	869	676	.8947	858	36
25	.24897	.25707	3.8900	.96851	35
26	925	738	.8854	844	34
27	954	769	.8807	837	33
28	.24982	800	.8760	829	32
29	.25010	831	.8714	822	31
30	.25038	.25862	3.8667	.96815	30
31	066	893	.8621	807	29
32	094	924	.8575	800	28
33	122	955	.8528	793	27
34	151	.25986	.8482	786	26
35	.25179	.26017	3.8436	.96778	25
36	207	048	.8391	771	24
37	235	079	.8345	764	23
38	263	110	.8299	756	22
39	291	141	.8254	749	21
40	.25320	.26172	3.8208	.96742	20
41	348	203	.8163	734	19
42	376	235	.8118	727	18
43	404	266	.8073	719	17
44	432	297	.8028	712	16
45	.25460	.26328	3.7983	.96705	15
46	488	359	.7938	697	14
47	516	390	.7893	690	13
48	545	421	.7848	682	12
49	573	452	7804	675	11
50	.25601	.26483	3.7760	.96667	10
51	629	515	.7715	660	9
52	657	546	.7671	653	8
53	685	577	.7627	645	7
54	713	608	7583	638	6
55	.25741	26639	3.7539	96630	5
56	769	670	.7495	623	4
57	798	701	.7451	615	3
58	826	733	.7408	608	2
59	854	764	.7364	600	1
60	.25882	.26795	3.7321	.96593	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.25882	.26795	3.7321	.96593	60
1	910	826	.7277	585	59
2	938	857	.7234	578	58
3	966	888	.7191	570	57
4	.25994	920	.7148	562	56
5	.26022	.26951	3.7105	.96555	55
6	050	.26982	.7062	547	54
7	079	.27013	.7019	540	53
8	107	044	.6976	532	52
9	135	076	.6933	524	51
10	.26163	.27107	3.6891	.96517	50
11	191	138	.6848	509	49
12	219	169	.6806	502	48
13	247	201	.6764	494	47
14	275	232	.6722	486	46
15	.26303	.27263	3.6680	.96479	45
16	331	294	.6638	471	44
17	359	326	.6596	463	43
18	387	357	.6554	456	42
19	415	388	.6512	448	41
20	.26443	.27419	3.6470	.96440	40
21	471	451	.6429	433	39
22	500	482	.6387	425	38
23	528	513	.6346	417	37
24	556	545	.6305	410	36
25	.26584	.27576	3.6264	.96402	35
26	612	607	.6222	394	34
27	640	638	.6181	386	33
28	668	670	.6140	379	32
29	696	701	.6100	371	31
30	.26724	.27732	3.6059	.96363	30
31	752	764	.6018	355	29
32	780	795	.5978	347	28
33	808	826	.5937	340	27
34	836	858	.5897	332	26
35	.26864	.27889	3.5856	.96324	25
36	892	921	.5816	316	24
37	920	952	.5776	308	23
38	948	.27983	.5736	301	22
39	.26976	.28015	.5696	293	21
40	.27004	.28046	3.5656	.96285	20
41	032	077	.5616	277	19
42	060	109	.5576	269	18
43	088	140	.5536	261	17
44	116	172	.5497	253	16
45	.27144	.28203	3.5457	.96246	15
46	172	234	.5418	238	14
47	200	266	.5379	230	13
48	228	297	.5339	222	12
49	256	329	.5300	214	11
50	.27284	.28360	3.5261	.96206	10
51	312	391	.5222	198	9
52	340	423	.5183	190	8
53	368	454	.5144	182	7
54	396	486	.5105	174	6
55	27424	.28517	3.5067	.96166	5
56	452	549	.5028	158	4
57	480	580	.4989	150	3
58	508	612	.4951	142	2
59	536	643	.4912	134	1
60	.27564	.28675	3.4874	.96126	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.27564	.28675	3.4874	96126	60
1	592	706	.4836	118	59
2	620	738	.4798	110	58
3	648	769	.4760	102	57
4	676	801	.4722	094	56
5	.27704	.28832	3.4684	.96086	55
6	731	864	.4646	078	54
7	759	895	.4608	070	53
8	787	927	.4570	062	52
9	815	958	.4533	054	51
10	.27843	.28990	3.4495	.96046	50
11	871	.29021	.4458	037	49
12	899	053	.4420	029	48
13	927	084	.4383	021	47
14	955	116	.4346	013	46
15	.27983	.29147	3.4308	.96005	45
16	.28011	179	.4271	.95997	44
17	039	210	.4234	989	43
18	067	242	.4197	981	42
19	095	274	.4160	972	41
20	.28123	.29305	3.4124	.95964	40
21	150	337	.4087	956	39
22	178	368	.4050	948	38
23	206	400	.4014	940	37
24	234	432	.3977	931	36
25	.28262	.29463	3.3941	.95923	35
26	290	495	.3904	915	34
27	318	526	.3868	907	33
28	346	558	.3832	898	32
29	374	590	.3796	890	31
30	.28402	.29621	3.3759	.95882	30
31	429	653	.3723	874	29
32	457	685	.3687	865	28
33	485	716	.3652	857	27
34	513	748	.3616	849	26
35	.28541	.29780	3.3580	.95841	25
36	569	811	.3544	832	24
37	597	843	.3509	824	23
38	625	875	.3473	816	22
39	652	906	.3438	807	21
40	.28680	.29938	3.3402	.95799	20
41	708	.29970	.3367	791	19
42	736	.30001	.3332	782	18
43	764	033	.3297	774	17
44	792	065	.3261	766	16
45	.28820	.30097	3.3226	.95757	15
46	847	128	.3191	749	14
47	875	160	.3156	740	13
48	903	192	.3122	732	12
49	931	224	.3087	724	11
50	.28959	.30255	3.3052	.95715	10
51	.28987	287	.3017	707	9
52	.29015	319	.2983	698	8
53	042	351	.2948	690	7
54	070	382	.2914	681	6
55	.29098	.30414	3.2879	.95673	5
56	126	446	.2845	664	4
57	154	478	.2811	656	3
58	182	509	.2777	647	2
59	209	541	.2743	639	1
60	.29237	.30573	3.2709	.95630	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	29237	30573	3.2709	95630	60
1	265	605	.2675	622	59
2	293	637	.2641	613	58
3	321	669	.2607	605	57
4	348	700	.2573	596	56
5	.29376	30732	3.2539	.95588	55
6	404	764	.2506	579	54
7	432	796	.2472	571	53
8	460	828	.2438	562	52
9	487	860	.2405	554	51
10	.29515	.30891	3.2371	.95545	50
11	543	923	.2338	536	49
12	571	955	.2305	528	48
13	599	.30987	.2272	519	47
14	626	.31019	.2238	511	46
15	.29654	.31051	3.2205	.95502	45
16	682	083	.2172	493	44
17	710	115	.2139	485	43
18	737	147	.2106	476	42
19	765	178	.2073	467	41
20	.29793	.31210	3.2041	.95459	40
21	821	242	.2008	450	39
22	849	274	.1975	441	38
23	876	306	.1943	433	37
24	904	338	.1910	424	36
25	.29932	.31370	3.1878	.95415	35
26	960	402	.1845	407	34
27	.29987	434	.1813	398	33
28	.30015	466	.1780	389	32
29	043	498	.1748	380	31
30	.30071	.31530	3.1716	.95372	30
31	098	562	.1684	363	29
32	126	594	.1652	354	28
33	154	626	.1620	345	27
34	182	658	.1588	337	26
35	.30209	.31690	3.1556	.95328	25
36	237	722	.1524	319	24
37	265	754	.1492	310	23
38	292	786	.1460	301	22
39	320	818	.1429	293	21
40	.30348	.31850	3.1397	.95284	20
41	376	882	.1366	275	19
42	403	914	.1334	260	18
43	431	946	.1303	257	17
44	459	.31978	.1271	248	16
45	.30486	.32010	3.1240	.95240	15
46	514	042	.1209	231	14
47	542	074	.1178	222	13
48	570	106	.1146	213	12
49	597	139	.1115	204	11
50	.30625	.32171	3.1084	.95195	10
51	653	203	.1053	186	9
52	680	235	.1022	177	8
53	708	267	.0991	168	7
54	736	299	.0961	159	6
55	.30763	.32331	3.0930	.95150	5
56	791	363	.0899	142	4
57	819	396	.0868	133	3
58	846	428	.0838	124	2
59	874	460	.0807	115	1
60	.30902	.32492	3.0777	.95106	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.30902	32492	3 0777	.95106	60
1	929	524	.0746	097	59
2	957	556	.0716	088	58
3	.30985	588	.0686	079	57
4	.31012	621	.0655	070	56
5	.31040	.32653	3.0625	.95061	55
6	068	685	.0595	052	54
7	095	717	.0565	043	53
8	123	749	.0535	033	52
9	151	782	.0505	024	51
10	.31178	.32814	3.0475	.95015	50
11	206	846	.0445	.95006	49
12	233	878	.0415	.94997	48
13	261	911	.0385	988	47
14	289	943	.0356	979	46
15	.31316	.32975	3.0326	.94970	45
16	344	.33007	.0296	961	44
17	372	040	.0267	952	43
18	399	072	.0237	943	42
19	427	104	.0208	933	41
20	.31454	.33136	3.0178	.94924	40
21	482	169	.0149	915	39
22	510	201	.0120	906	38
23	537	233	.0090	897	37
24	565	266	.0061	888	36
25	.31593	.33298	3.0032	.94878	35
26	620	330	3.0003	869	34
27	648	363	2.9974	860	33
28	675	395	.9945	851	32
29	703	427	.9916	842	31
30	.31730	.33460	2.9887	94832	30
31	758	492	.9858	823	29
32	786	524	.9829	814	28
33	813	557	.9800	805	27
34	841	589	.9772	795	26
35	.31868	.33621	2.9743	.94786	25
36	896	654	.9714	777	24
37	923	686	.9686	768	23
38	951	718	.9657	758	22
39	.31979	751	.9629	749	21
40	.32006	33783	2.9600	94740	20
41	034	816	.9572	730	19
42	061	848	.9544	721	18
43	089	881	.9515	712	17
44	116	913	.9487	702	16
45	.32144	.33945	2.9459	.94693	15
46	171	.33978	.9431	684	14
47	199	.34010	.9403	674	13
48	227	043	.9375	665	12
49	254	075	.9347	656	11
50	.32282	.34108	2.9319	.94646	10
51	309	140	.9291	637	9
52	337	173	.9263	627	8
53	364	205	.9235	618	7
54	392	238	.9208	609	6
55	.32419	.34270	2.9180	.94599	5
56	447	303	.9152	590	4
57	474	335	.9125	580	3
58	502	368	.9097	571	2
59	529	400	.9070	561	1
60	.32557	.34433	2.9042	.94552	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	32557	34433	2.9042	94552	60
1	584	465	.9015	542	59
2	612	498	.8987	533	58
3	639	530	.8960	523	57
4	667	563	.8933	514	56
5	.32694	34596	2.8905	.94504	55
6	722	628	.8878	495	54
7	749	661	.8851	485	53
8	777	693	.8824	476	52
9	804	726	.8797	466	51
10	.32832	.34758	2.8770	.94457	50
11	859	791	.8743	447	49
12	887	824	.8716	438	48
13	914	856	.8689	428	47
14	942	889	.8662	418	46
15	.32969	.34922	2 8636	94409	45
16	.32997	954	.8609	399	44
17	.33024	.34987	.8582	390	43
18	051	.35020	.8556	380	42
19	079	052	.8529	370	41
20	.33106	.35085	2.8502	.94361	40
21	134	118	.8476	351	39
22	161	150	8449	342	38
23	189	183	.8423	332	37
24	216	216	8397	322	36
25	.33244	.35248	2 8370	94313	35
26	271	281	.8344	303	34
27	298	314	.8318	293	33
28	326	346	8291	284	32
29	353	379	8265	274	31
30	33381	35412	2 8239	94264	30
31	408	445	.8213	254	29
32	436	477	8187	245	28
33	463	510	8161	235	27
34	490	543	.8135	225	26
35	33518	35576	2 8109	94215	25
36	545	608	8083	206	24
37	573	641	8057	196	23
38	600	674	.8032	186	22
39	627	707	.8006	176	21
40	33655	.35740	2 7980	94167	20
41	682	772	7955	157	19
42	710	805	7929	147	18
43	737	838	7903	137	17
44	764	871	7878	127	16
45	33792	35904	2 7852	94118	15
46	819	937	7827	108	14
47	846	35969	7801	098	13
48	874	36002	7776	088	12
49	901	035	7751	078	11
50	33929	36068	2 7725	94068	10
51	956	101	7700	058	9
52	.33983	134	.7675	049	8
53	34011	167	7650	039	7
54	038	199	.7625	029	6
55	34065	36232	2.7600	94019	5
56	093	265	.7575	94009	4
57	120	298	7550	.93999	3
58	147	331	7525	989	2
59	175	364	7500	979	1
60	.34202	.36397	2 7475	.93969	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.34202	.36397	2.7475	93969	60
1	229	430	.7450	959	59
2	257	463	.7425	949	58
3	284	496	.7400	939	57
4	311	529	.7376	929	56
5	.34339	.36562	2.7351	93919	55
6	366	595	.7326	909	54
7	393	628	.7302	899	53
8	421	661	.7277	889	52
9	448	694	.7253	879	51
10	.34475	.36727	2.7228	.93869	50
11	503	760	.7204	859	49
12	530	793	.7179	849	48
13	557	826	.7155	839	47
14	584	859	.7130	829	46
15	.34612	36892	2.7106	93819	45
16	639	925	.7082	809	44
17	666	958	.7058	799	43
18	694	.36991	.7034	789	42
19	721	.37024	.7009	779	41
20	.34748	37057	2.6985	93769	40
21	775	090	.6961	759	39
22	803	123	.6937	748	38
23	830	157	.6913	738	37
24	857	190	.6889	728	36
25	.34884	.37223	2.6865	.93718	35
26	912	256	.6841	708	34
27	939	289	.6818	698	33
28	966	322	.6794	688	32
29	.34993	355	.6770	677	31
30	.35021	.37388	2.6746	.93667	30
31	048	422	.6723	657	29
32	075	455	.6699	647	28
33	102	488	.6675	637	27
34	130	521	.6652	626	26
35	.35157	.37554	2.6628	.93616	25
36	184	588	.6605	606	24
37	211	621	.6581	596	23
38	239	654	.6558	585	22
39	266	687	.6534	575	21
40	.35293	.37720	2.6511	.93565	20
41	320	754	.6488	555	19
42	347	787	.6464	544	18
43	375	820	.6441	534	17
44	402	853	.6418	524	16
45	.35429	.37887	2.6395	.93514	15
46	456	920	.6371	503	14
47	484	953	.6348	493	13
48	511	.37986	.6325	483	12
49	538	.38020	.6302	472	11
50	.35565	.38053	2.6279	.93462	10
51	592	086	.6256	452	9
52	619	120	.6233	441	8
53	647	153	.6210	431	7
54	674	186	.6187	420	6
55	.35701	.38220	2.6165	.93410	5
56	728	253	.6142	400	4
57	755	286	.6119	389	3
58	782	320	.6096	379	2
59	810	353	.6074	368	1
60	.35837	.38386	2.6051	.93358	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.35837	.38386	2.6051	.93358	60
1	864	420	.6028	348	59
2	891	453	.6006	337	58
3	918	487	.5983	327	57
4	945	520	.5961	316	56
5	.35973	.38553	2.5938	.93306	55
6	.36000	587	.5916	295	54
7	027	620	.5893	285	53
8	054	654	.5871	274	52
9	081	687	.5848	264	51
10	36108	.38721	2.5826	.93253	50
11	135	754	.5804	243	49
12	162	787	.5782	232	48
13	190	821	.5759	222	47
14	217	854	.5737	211	46
15	36244	38888	2.5715	.93201	45
16	271	921	.5693	190	44
17	298	955	.5671	180	43
18	325	38988	.5649	169	42
19	352	.39022	.5627	159	41
20	.36379	.39055	2.5605	93148	40
21	406	089	.5583	137	39
22	434	122	5561	127	38
23	461	156	.5539	116	37
24	488	190	.5517	106	36
25	.36515	.39223	2.5495	93095	35
26	542	257	5473	084	34
27	569	290	.5452	074	33
28	596	324	.5430	063	32
29	623	357	.5408	052	31
30	.36650	.39391	2.5386	93042	30
31	677	425	.5365	031	29
32	704	458	.5343	020	28
33	731	492	.5322	.93010	27
34	758	526	.5300	.92999	26
35	.36785	.39559	2.5279	.92988	25
36	812	593	.5257	978	24
37	839	626	.5236	967	23
38	867	660	.5214	956	22
39	894	694	.5193	945	21
40	.36921	.39727	2.5172	.92935	20
41	948	761	.5150	924	19
42	.36975	795	.5129	913	18
43	.37002	829	5108	902	17
44	029	862	.5086	892	16
45	.37056	.39896	2.5065	.92881	15
46	083	930	.5044	870	14
47	110	963	.5023	859	13
48	137	.39997	.5002	849	12
49	164	.40031	.4981	838	11
50	.37191	.40065	2.4960	.92827	10
51	218	098	.4939	816	9
52	245	132	.4918	805	8
53	272	166	.4897	794	7
54	299	200	.4876	784	6
55	.37326	.40234	2.4855	.92773	5
56	353	267	.4834	762	4
57	380	301	.4813	751	3
58	407	335	.4792	740	2
59	434	369	.4772	729	1
60	.37461	.40403	2.4751	.92718	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.37461	.40403	2.4751	.92718	60
1	488	436	.4730	707	59
2	515	470	.4709	697	58
3	542	504	.4689	686	57
4	569	538	.4668	675	56
5	.37595	.40572	2.4648	.92664	55
6	622	606	.4627	653	54
7	649	640	.4606	642	53
8	676	674	.4586	631	52
9	703	707	.4566	620	51
10	.37730	.40741	2.4545	.92609	50
11	757	775	.4525	598	49
12	784	809	.4504	587	48
13	811	843	.4484	576	47
14	838	877	.4464	565	46
15	.37865	.40911	2.4443	.92554	45
16	892	945	.4423	543	44
17	919	.40979	.4403	532	43
18	946	.41013	.4383	521	42
19	973	047	.4362	510	41
20	.37999	.41081	2.4342	.92499	40
21	.38026	115	.4322	488	39
22	053	149	.4302	477	38
23	080	183	.4282	466	37
24	107	217	.4262	455	36
25	.38134	.41251	2.4242	.92444	35
26	161	285	.4222	432	34
27	188	319	.4202	421	33
28	215	353	.4182	410	32
29	241	387	.4162	399	31
30	.38268	.41421	2.4142	.92388	30
31	295	455	.4122	377	29
32	322	490	.4102	366	28
33	349	524	.4083	355	27
34	376	558	.4063	343	26
35	.38403	.41592	2.4043	.92332	25
36	430	626	.4023	321	24
37	456	660	.4004	310	23
38	483	694	.3984	299	22
39	510	728	.3964	287	21
40	.38537	.41763	2.3945	.92276	20
41	564	797	.3925	265	19
42	591	831	.3906	254	18
43	617	865	.3886	243	17
44	644	899	.3867	231	16
45	.38671	.41933	2.3847	.92220	15
46	698	.41968	.3828	209	14
47	725	.42002	.3808	198	13
48	752	036	.3789	186	12
49	778	070	.3770	175	11
50	.38805	.42105	2.3750	.92164	10
51	832	139	.3731	152	9
52	859	173	.3712	141	8
53	886	207	.3693	130	7
54	912	242	.3673	119	6
55	.38939	.42276	2.3654	.92107	5
56	966	310	.3635	096	4
57	.38993	345	.3616	085	3
58	.39020	379	.3597	073	2
59	046	413	.3578	062	1
60	.39073	.42447	2.3559	.92050	0
	cos	cot	tan	sin	′

157° 247° 337° **67°**

′	sin	tan	cot	cos	
0	.39073	.42447	2.3559	.92050	60
1	100	482	.3539	039	59
2	127	516	.3520	028	58
3	153	551	.3501	016	57
4	180	585	.3483	.92005	56
5	.39207	.42619	2.3464	.91994	55
6	234	654	.3445	982	54
7	260	688	.3426	971	53
8	287	722	.3407	959	52
9	314	757	.3388	948	51
10	.39341	.42791	2.3369	.91936	50
11	367	826	.3351	925	49
12	394	860	.3332	914	48
13	421	894	.3313	902	47
14	448	929	.3294	891	46
15	.39474	.42963	2.3276	.91879	45
16	501	.42998	.3257	868	44
17	528	.43032	.3238	856	43
18	555	067	.3220	845	42
19	581	101	.3201	833	41
20	.39608	.43136	2.3183	.91822	40
21	635	170	.3164	810	39
22	661	205	.3146	799	38
23	688	239	.3127	787	37
24	715	274	.3109	775	36
25	.39741	.43308	2.3090	.91764	35
26	768	343	.3072	752	34
27	795	378	.3053	741	33
28	822	412	.3035	729	32
29	848	447	.3017	718	31
30	.39875	.43481	2.2998	.91706	30
31	902	516	.2980	694	29
32	928	550	.2962	683	28
33	955	585	.2944	671	27
34	.39982	620	.2925	660	26
35	.40008	.43654	2.2907	.91648	25
36	035	689	.2889	636	24
37	062	724	.2871	625	23
38	088	758	.2853	613	22
39	115	793	.2835	601	21
40	.40141	.43828	2.2817	.91590	20
41	168	862	.2799	578	19
42	195	897	.2781	566	18
43	221	932	.2763	555	17
44	248	.43966	.2745	543	16
45	.40275	.44001	2.2727	.91531	15
46	301	036	.2709	519	14
47	328	071	.2691	508	13
48	355	105	.2673	496	12
49	381	140	.2655	484	11
50	.40408	.44175	2.2637	.91472	10
51	434	210	.2620	461	9
52	461	244	.2602	449	8
53	488	279	.2584	437	7
54	514	314	.2566	425	6
55	.40541	.44349	2.2549	.91414	5
56	567	384	.2531	402	4
57	594	418	.2513	390	3
58	621	453	.2496	378	2
59	647	488	.2478	366	1
60	.40674	.44523	2.2460	.91355	0
	cos	cot	tan	sin	′

66° 156° 246° 336°

'	sin	tan	cot	cos	
0	.40674	.44523	2.2460	.91355	60
1	700	558	.2443	343	59
2	727	593	.2425	331	58
3	753	627	.2408	319	57
4	780	662	.2390	307	56
5	.40806	.44697	2.2373	.91295	55
6	833	732	.2355	283	54
7	860	767	.2338	272	53
8	886	802	.2320	260	52
9	913	837	.2303	248	51
10	.40939	.44872	2.2286	.91236	50
11	966	907	.2268	224	49
12	.40992	942	2251	212	48
13	.41019	.44977	.2234	200	47
14	045	.45012	.2216	188	46
15	.41072	.45047	2.2199	.91176	45
16	098	082	.2182	164	44
17	125	117	.2165	152	43
18	151	152	.2148	140	42
19	178	187	.2130	128	41
20	.41204	.45222	2.2113	.91116	40
21	231	257	.2096	104	39
22	257	292	.2079	092	38
23	284	327	2062	080	37
24	310	362	.2045	068	36
25	.41337	.45397	2.2028	.91056	35
26	363	432	2011	044	34
27	390	467	1994	032	33
28	416	502	1977	020	32
29	443	538	1960	.91008	31
30	.41469	.45573	2.1943	90996	30
31	496	608	.1926	984	29
32	522	643	.1909	972	28
33	549	678	.1892	960	27
34	575	713	1876	948	26
35	.41602	.45748	2.1859	.90936	25
36	628	784	.1842	924	24
37	655	819	1825	911	23
38	681	854	1808	899	22
39	707	889	1792	887	21
40	.41734	.45924	2.1775	.90875	20
41	760	960	1758	863	19
42	787	.45995	1742	851	18
43	813	.46030	1725	839	17
44	840	065	.1708	826	16
45	.41866	.46101	2.1692	.90814	15
46	892	136	.1675	802	14
47	919	171	1659	790	13
48	945	206	.1642	778	12
49	972	242	.1625	766	11
50	.41998	.46277	2.1609	.90753	10
51	.42024	312	.1592	741	9
52	051	348	.1576	729	8
53	077	383	.1560	717	7
54	104	418	.1543	704	6
55	.42130	.46454	2.1527	.90692	5
56	156	489	.1510	680	4
57	183	525	.1494	668	3
58	209	560	.1478	655	2
59	235	595	.1461	643	1
60	.42262	.46631	2.1445	.90631	0
	cos	cot	tan	sin	'

'	sin	tan	cot	cos	
0	.42262	.46631	2.1445	.90631	60
1	288	666	.1429	618	59
2	315	702	.1413	606	58
3	341	737	.1396	594	57
4	367	772	.1380	582	56
5	.42394	.46808	2.1364	.90569	55
6	420	843	.1348	557	54
7	446	879	.1332	545	53
8	473	914	.1315	532	52
9	499	950	.1299	520	51
10	.42525	.46985	2.1283	.90507	50
11	552	.47021	.1267	495	49
12	578	056	.1251	483	48
13	604	092	.1235	470	47
14	631	128	.1219	458	46
15	.42657	.47163	2.1203	.90446	45
16	683	199	.1187	433	44
17	709	234	.1171	421	43
18	736	270	.1155	408	42
19	762	305	.1139	396	41
20	.42788	.47341	2.1123	.90383	40
21	815	377	.1107	371	39
22	841	412	.1092	358	38
23	867	448	.1076	346	37
24	894	483	.1060	334	36
25	.42920	.47519	2.1044	.90321	35
26	946	555	.1028	309	34
27	972	590	.1013	296	33
28	.42999	626	0997	284	32
29	.43025	662	.0981	271	31
30	.43051	.47698	2.0965	.90259	30
31	077	733	.0950	246	29
32	104	769	.0934	233	28
33	130	805	.0918	221	27
34	156	840	.0903	208	26
35	.43182	.47876	2.0887	.90196	25
36	209	912	.0872	183	24
37	235	948	.0856	171	23
38	261	.47984	.0840	158	22
39	287	.48019	.0825	146	21
40	.43313	.48055	2.0809	.90133	20
41	340	091	.0794	120	19
42	366	127	.0778	108	18
43	392	163	.0763	095	17
44	418	198	.0748	082	16
45	.43445	.48234	2.0732	.90070	15
46	471	270	.0717	057	14
47	497	306	.0701	045	13
48	523	342	.0686	032	12
49	549	378	.0671	019	11
50	.43575	.48414	2.0655	.90007	10
51	602	450	.0640	.89994	9
52	628	486	.0625	981	8
53	654	521	.0609	968	7
54	680	557	.0594	956	6
55	.43706	.48593	2.0579	.89943	5
56	733	629	.0564	930	4
57	759	665	.0549	918	3
58	785	701	.0533	905	2
59	811	737	.0518	892	1
60	.43837	.48773	2.0503	.89879	0
	cos	cot	tan	sin	'

′	sin	tan	cot	cos	
0	.43837	.48773	2.0503	.89879	60
1	863	809	.0488	867	59
2	889	845	.0473	854	58
3	916	881	.0458	841	57
4	942	917	.0443	828	56
5	.43968	.48953	2.0428	.89816	**55**
6	.43994	.48989	.0413	803	54
7	.44020	.49026	.0398	790	53
8	046	062	.0383	777	52
9	072	098	.0368	764	51
10	.44098	.49134	2.0353	.89752	**50**
11	124	170	.0338	739	49
12	151	206	.0323	726	48
13	177	242	.0308	713	47
14	203	278	.0293	700	46
15	.44229	.49315	2.0278	.89687	**45**
16	255	351	.0263	674	44
17	281	387	.0248	662	43
18	307	423	.0233	649	42
19	333	459	.0219	636	41
20	.44359	.49495	2.0204	.89623	**40**
21	385	532	.0189	610	39
22	411	568	.0174	597	38
23	437	604	.0160	584	37
24	464	640	.0145	571	36
25	.44490	.49677	2.0130	.89558	**35**
26	516	713	.0115	545	34
27	542	749	.0101	532	33
28	568	786	.0086	519	32
29	594	822	.0072	506	31
30	.44620	.49858	2.0057	.89493	**30**
31	646	894	.0042	480	29
32	672	931	.0028	467	28
33	698	.49967	2.0013	454	27
34	724	.50004	1.9999	441	26
35	.44750	.50040	1.9984	.89428	**25**
36	776	076	.9970	415	24
37	802	113	.9955	402	23
38	828	149	.9941	389	22
39	854	185	.9926	376	21
40	.44880	.50222	1.9912	.89363	**20**
41	906	258	.9897	350	19
42	932	295	.9883	337	18
43	958	331	.9868	324	17
44	.44984	368	.9854	311	16
45	.45010	.50404	1.9840	.89298	**15**
46	036	441	.9825	285	14
47	062	477	.9811	272	13
48	088	514	.9797	259	12
49	114	550	.9782	245	11
50	.45140	.50587	1.9768	.89232	**10**
51	166	623	.9754	219	9
52	192	660	.9740	206	8
53	218	696	.9725	193	7
54	243	733	.9711	180	6
55	.45269	.50769	1.9697	.89167	**5**
56	295	806	.9683	153	4
57	321	843	.9669	140	3
58	347	879	.9654	127	2
59	373	916	.9640	114	1
60	.45399	.50953	1.9626	.89101	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.45399	.50953	1.9626	.89101	60
1	425	.50989	.9612	087	59
2	451	.51026	.9598	074	58
3	477	063	.9584	061	57
4	503	099	.9570	048	56
5	.45529	.51136	1.9556	.89035	**55**
6	554	173	.9542	021	54
7	580	209	.9528	.89008	53
8	606	246	.9514	.88995	52
9	632	283	.9500	981	51
10	.45658	.51319	1.9486	.88968	**50**
11	684	356	.9472	955	49
12	710	393	.9458	942	48
13	736	430	.9444	928	47
14	762	467	.9430	915	46
15	.45787	.51503	1.9416	.88902	**45**
16	813	540	.9402	888	44
17	839	577	.9388	875	43
18	865	614	.9375	862	42
19	891	651	.9361	848	41
20	.45917	.51688	1.9347	.88835	**40**
21	942	724	.9333	822	39
22	968	761	.9319	808	38
23	.45994	798	.9306	795	37
24	.46020	835	.9292	782	36
25	.46046	.51872	1.9278	.88768	**35**
26	072	909	.9265	755	34
27	097	946	.9251	741	33
28	123	.51983	.9237	728	32
29	149	.52020	.9223	715	31
30	.46175	.52057	1.9210	.88701	**30**
31	201	094	.9196	688	29
32	226	131	.9183	674	28
33	252	168	.9169	661	27
34	278	205	.9155	647	26
35	.46304	.52242	1.9142	.88634	**25**
36	330	279	.9128	620	24
37	355	316	.9115	607	23
38	381	353	.9101	593	22
39	407	390	.9088	580	21
40	.46433	.52427	1.9074	.88566	**20**
41	458	464	.9061	553	19
42	484	501	.9047	539	18
43	510	538	.9034	526	17
44	536	575	.9020	512	16
45	.46561	.52613	1.9007	.88499	**15**
46	587	650	.8993	485	14
47	613	687	.8980	472	13
48	639	724	.8967	458	12
49	664	761	.8953	445	11
50	.46690	.52798	1.8940	.88431	**10**
51	716	836	.8927	417	9
52	742	873	.8913	404	8
53	767	910	.8900	390	7
54	793	947	.8887	377	6
55	.46819	.52985	1.8873	.88363	**5**
56	844	.53022	.8860	349	4
57	870	059	.8847	336	3
58	896	096	.8834	322	2
59	921	134	.8820	308	1
60	.46947	.53171	1.8807	.88295	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.46947	.53171	1.8807	.88295	60
1	973	208	.8794	281	59
2	.46999	246	.8781	267	58
3	.47024	283	.8768	254	57
4	050	320	.8755	240	56
5	.47076	.53358	1.8741	.88226	55
6	101	395	.8728	213	54
7	127	432	.8715	199	53
8	153	470	.8702	185	52
9	178	507	.8689	172	51
10	.47204	.53545	1.8676	.88158	50
11	229	582	8663	144	49
12	255	620	.8650	130	48
13	281	657	.8637	117	47
14	306	694	.8624	103	46
15	.47332	.53732	1.8611	88089	45
16	358	769	.8598	075	44
17	383	807	8585	062	43
18	409	844	8572	048	42
19	434	882	.8559	034	41
20	.47460	53920	1.8546	.88020	40
21	486	957	.8533	.88006	39
22	511	.53995	.8520	.87993	38
23	537	.54032	.8507	979	37
24	562	070	.8495	965	36
25	.47588	54107	1.8482	.87951	35
26	614	145	.8469	937	34
27	639	183	.8456	923	33
28	665	220	.8443	909	32
29	690	258	.8430	896	31
30	.47716	.54296	1.8418	.87882	30
31	741	333	.8405	868	29
32	767	371	.8392	854	28
33	793	409	.8379	840	27
34	818	446	.8367	826	26
35	.47844	.54484	1.8354	.87812	25
36	869	522	.8341	798	24
37	895	560	.8329	784	23
38	920	597	8316	770	22
39	946	635	.8303	756	21
40	.47971	.54673	1 8291	87743	20
41	.47997	711	.8278	729	19
42	.48022	748	.8265	715	18
43	048	786	.8253	701	17
44	073	824	.8240	687	16
45	.48099	.54862	1.8228	87673	15
46	124	900	8215	659	14
47	150	938	8202	645	13
48	175	54975	.8190	631	12
49	201	.55013	.8177	617	11
50	.48226	.55051	1.8165	87603	10
51	252	089	.8152	589	9
52	277	127	.8140	575	8
53	303	165	.8127	561	7
54	328	203	.8115	546	6
55	.48354	.55241	1.8103	.87532	5
56	379	279	.8090	518	4
57	405	317	.8078	504	3
58	430	355	.8065	490	2
59	456	393	.8053	476	1
60	.48481	.55431	1.8040	.87462	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	48481	.55431	1.8040	.87462	60
1	506	469	.8028	448	59
2	532	507	.8016	434	58
3	557	545	.8003	420	57
4	583	583	.7991	406	56
5	48608	.55621	1.7979	.87391	55
6	634	659	.7966	377	54
7	659	697	.7954	363	53
8	684	736	.7942	349	52
9	710	774	.7930	335	51
10	48735	.55812	1.7917	.87321	50
11	761	850	.7905	306	49
12	786	888	.7893	292	48
13	811	926	.7881	278	47
14	837	55964	.7868	264	46
15	.48862	.56003	1.7856	.87250	45
16	888	041	.7844	235	44
17	913	079	.7832	221	43
18	938	117	.7820	207	42
19	964	156	.7808	193	41
20	.48989	.56194	1.7796	.87178	40
21	.49014	232	.7783	164	39
22	040	270	.7771	150	38
23	065	309	.7759	136	37
24	090	347	.7747	121	36
25	49116	.56385	1.7735	.87107	35
26	141	424	.7723	093	34
27	166	462	.7711	079	33
28	192	501	.7699	064	32
29	217	539	.7687	050	31
30	.49242	.56577	1.7675	.87036	30
31	268	616	.7663	021	29
32	293	654	.7651	.87007	28
33	318	693	.7639	.86993	27
34	344	731	7627	978	26
35	.49369	.56769	1.7615	.86964	25
36	394	808	.7603	949	24
37	419	846	.7591	935	23
38	445	885	.7579	921	22
39	470	923	.7567	906	21
40	.49495	.56962	1.7556	.86892	20
41	521	.57000	.7544	878	19
42	546	039	.7532	863	18
43	571	078	.7520	849	17
44	596	116	.7508	834	16
45	49622	.57155	1.7496	.86820	15
46	647	193	.7485	805	14
47	672	232	.7473	791	13
48	697	271	.7461	777	12
49	723	309	.7449	762	11
50	.49748	57348	1.7437	86748	10
51	773	386	.7426	733	9
52	798	425	.7414	719	8
53	824	464	.7402	704	7
54	849	503	.7391	690	6
55	.49874	.57541	1.7379	.86675	5
56	899	580	.7367	661	4
57	924	619	.7355	646	3
58	950	657	.7344	632	2
59	.49975	696	.7332	617	1
60	.50000	.57735	1.7321	.86603	0
	cos	cot	tan	sin	′

120° 210° 300° **30°**

′	sin	tan	cot	cos	′
0	.50000	.57735	1.7321	.86603	60
1	025	774	.7309	588	59
2	050	813	.7297	573	58
3	076	851	.7286	559	57
4	101	890	.7274	544	56
5	.50126	.57929	1.7262	.86530	55
6	151	.57968	.7251	515	54
7	176	.58007	.7239	501	53
8	201	046	.7228	486	52
9	227	085	.7216	471	51
10	.50252	.58124	1.7205	.86457	50
11	277	162	.7193	442	49
12	302	201	.7182	427	48
13	327	240	.7170	413	47
14	352	279	.7159	398	46
15	.50377	.58318	1.7147	.86384	45
16	403	357	.7136	369	44
17	428	396	.7124	354	43
18	453	435	.7113	340	42
19	478	474	.7102	325	41
20	.50503	.58513	1.7090	.86310	40
21	528	552	.7079	295	39
22	553	591	.7067	281	38
23	578	631	.7056	266	37
24	603	670	.7045	251	36
25	.50628	.58709	1.7033	.86237	35
26	654	748	.7022	222	34
27	679	787	.7011	207	33
28	704	826	.6999	192	32
29	729	865	.6988	178	31
30	.50754	.58905	1.6977	.86163	30
31	779	944	.6965	148	29
32	804	.58983	.6954	133	28
33	829	.59022	.6943	119	27
34	854	061	.6932	104	26
35	.50879	.59101	1.6920	.86089	25
36	904	140	.6909	074	24
37	929	179	.6898	059	23
38	954	218	.6887	045	22
39	.50979	258	.6875	030	21
40	.51004	.59297	1.6864	.86015	20
41	029	336	.6853	.86000	19
42	054	376	.6842	.85985	18
43	079	415	.6831	970	17
44	104	454	.6820	956	16
45	.51129	.59494	1.6808	.85941	15
46	154	533	.6797	926	14
47	179	573	.6786	911	13
48	204	612	.6775	896	12
49	229	651	.6764	881	11
50	.51254	.59691	1.6753	.85866	10
51	279	730	.6742	851	9
52	304	770	.6731	836	8
53	329	809	.6720	821	7
54	354	849	.6709	806	6
55	.51379	.59888	1.6698	.85792	5
56	404	928	.6687	777	4
57	429	.59967	.6676	762	3
58	454	.60007	.6665	747	2
59	479	046	.6654	732	1
60	.51504	.60086	1.6643	.85717	0
′	cos	cot	tan	sin	′

149° 239° 329° **59°**

31° 121° 211° 301°

′	sin	tan	cot	cos	′
0	.51504	.60086	1.6643	.85717	60
1	529	126	.6632	702	59
2	554	165	.6621	687	58
3	579	205	.6610	672	57
4	604	245	.6599	657	56
5	.51628	.60284	1.6588	.85642	55
6	653	324	.6577	627	54
7	678	364	.6566	612	53
8	703	403	.6555	597	52
9	728	443	.6545	582	51
10	.51753	.60483	1.6534	.85567	50
11	778	522	.6523	551	49
12	803	562	.6512	536	48
13	828	602	.6501	521	47
14	852	642	.6490	506	46
15	.51877	.60681	1.6479	.85491	45
16	902	721	.6469	476	44
17	927	761	.6458	461	43
18	952	801	.6447	446	42
19	.51977	841	.6436	431	41
20	.52002	.60881	1.6426	.85416	40
21	026	921	.6415	401	39
22	051	.60960	.6404	385	38
23	076	.61000	.6393	370	37
24	101	040	.6383	355	36
25	.52126	.61080	1.6372	.85340	35
26	151	120	.6361	325	34
27	175	160	.6351	310	33
28	200	200	.6340	294	32
29	225	240	.6329	279	31
30	.52250	.61280	1.6319	.85264	30
31	275	320	.6308	249	29
32	299	360	.6297	234	28
33	324	400	.6287	218	27
34	349	440	.6276	203	26
35	.52374	.61480	1.6265	.85188	25
36	399	520	.6255	173	24
37	423	561	.6244	157	23
38	448	601	.6234	142	22
39	473	641	.6223	127	21
40	.52498	.61681	1.6212	.85112	20
41	522	721	.6202	096	19
42	547	761	.6191	081	18
43	572	801	.6181	066	17
44	597	842	.6170	051	16
45	.52621	.61882	1.6160	.85035	15
46	646	922	.6149	020	14
47	671	.61962	.6139	.85005	13
48	696	.62003	.6128	.84989	12
49	720	043	.6118	974	11
50	.52745	.62083	1.6107	.84959	10
51	770	124	.6097	943	9
52	794	164	.6087	928	8
53	819	204	.6076	913	7
54	844	245	.6066	897	6
55	.52869	.62285	1.6055	.84882	5
56	893	325	.6045	866	4
57	918	366	.6034	851	3
58	943	406	.6024	836	2
59	967	446	.6014	820	1
60	.52992	.62487	1.6003	.84805	0
′	cos	cot	tan	sin	′

58° 148° 238° 328°

′	sin	tan	cot	cos	
0	.52992	62487	1.6003	.84805	60
1	.53017	527	.5993	789	59
2	041	568	.5983	774	58
3	066	608	.5972	759	57
4	091	649	.5962	743	56
5	53115	.62689	1.5952	.84728	55
6	140	730	.5941	712	54
7	164	770	.5931	697	53
8	189	811	.5921	681	52
9	214	852	.5911	666	51
10	.53238	.62892	1.5900	.84650	50
11	263	933	.5890	635	49
12	288	.62973	.5880	619	48
13	312	.63014	.5869	604	47
14	337	055	.5859	588	46
15	.53361	.63095	1.5849	.84573	45
16	386	136	.5839	557	44
17	411	177	.5829	542	43
18	435	217	.5818	526	42
19	460	258	.5808	511	41
20	.53484	.63299	1.5798	.84495	40
21	509	340	.5788	480	39
22	534	380	.5778	464	38
23	558	421	.5768	448	37
24	583	462	.5757	433	36
25	.53607	.63503	1.5747	.84417	35
26	632	544	.5737	402	34
27	656	584	.5727	386	33
28	681	625	.5717	370	32
29	705	666	.5707	355	31
30	.53730	.63707	1.5697	.84339	30
31	754	748	.5687	324	29
32	779	789	.5677	308	28
33	804	830	.5667	292	27
34	828	871	.5657	277	26
35	.53853	.63912	1.5647	84261	25
36	877	953	.5637	245	24
37	902	.63994	.5627	230	23
38	926	.64035	.5617	214	22
39	951	076	.5607	198	21
40	.53975	.64117	1.5597	84182	20
41	.54000	158	.5587	167	19
42	024	199	.5577	151	18
43	049	240	.5567	135	17
44	073	281	.5557	120	16
45	.54097	.64322	1.5547	.84104	15
46	122	363	.5537	088	14
47	146	404	.5527	072	13
48	171	446	.5517	057	12
49	195	487	.5507	041	11
50	.54220	.64528	1.5497	.84025	10
51	244	569	.5487	.84009	9
52	269	610	.5477	.83994	8
53	293	652	.5468	978	7
54	317	693	.5458	962	6
55	.54342	.64734	1.5448	.83946	5
56	366	775	.5438	930	4
57	391	817	.5428	915	3
58	415	858	.5418	899	2
59	440	899	.5408	883	1
60	.54464	.64941	1.5399	.83867	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.54464	.64941	1.5399	.83867	60
1	488	.64982	.5389	851	59
2	513	.65024	.5379	835	58
3	537	065	.5369	819	57
4	561	106	.5359	804	56
5	.54586	.65148	1.5350	.83788	55
6	610	189	.5340	772	54
7	635	231	.5330	756	53
8	659	272	.5320	740	52
9	683	314	.5311	724	51
10	.54708	.65355	1.5301	.83708	50
11	732	397	.5291	692	49
12	756	438	.5282	676	48
13	781	480	.5272	660	47
14	805	521	.5262	645	46
15	.54829	.65563	1.5253	.83629	45
16	854	604	.5243	613	44
17	878	646	.5233	597	43
18	902	688	.5224	581	42
19	927	729	.5214	565	41
20	.54951	.65771	1.5204	.83549	40
21	975	813	.5195	533	39
22	.54999	854	.5185	517	38
23	.55024	896	.5175	501	37
24	048	938	.5166	485	36
25	.55072	.65980	1.5156	.83469	35
26	097	.66021	.5147	453	34
27	121	063	.5137	437	33
28	145	105	.5127	421	32
29	169	147	.5118	405	31
30	.55194	.66189	1.5108	.83389	30
31	218	230	.5099	373	29
32	242	272	.5089	356	28
33	266	314	.5080	340	27
34	291	356	.5070	324	26
35	.55315	66398	1.5061	.83308	25
36	339	440	.5051	292	24
37	363	482	.5042	276	23
38	388	524	.5032	260	22
39	412	566	.5023	244	21
40	.55436	66608	1.5013	83228	20
41	460	650	.5004	212	19
42	484	692	.4994	195	18
43	509	734	.4985	179	17
44	533	776	.4975	163	16
45	.55557	.66818	1.4966	.83147	15
46	581	860	.4957	131	14
47	605	902	.4947	115	13
48	630	944	.4938	098	12
49	654	.66986	.4928	082	11
50	.55678	.67028	1.4919	83066	10
51	702	071	.4910	050	9
52	726	113	.4900	034	8
53	750	155	.4891	017	7
54	775	197	.4882	.83001	6
55	.55799	.67239	1.4872	.82985	5
56	823	282	.4863	969	4
57	847	324	.4854	953	3
58	871	366	.4844	936	2
59	895	409	.4835	920	1
60	.55919	.67451	1.4826	.82904	0
	cos	cot	tan	sin	′

124° 214° 304° **34°** TABLE I.—*Continued.* **35°** 125° 215° 305°

′	sin	tan	cot	cos	
0	.55919	.67451	1.4826	.82904	60
1	943	493	.4816	887	59
2	968	536	.4807	871	58
3	.55992	578	.4798	855	57
4	.56016	620	.4788	839	56
5	.56040	.67663	1.4779	.82822	55
6	064	705	.4770	806	54
7	088	748	.4761	790	53
8	112	790	.4751	773	52
9	136	832	.4742	757	51
10	.56160	.67875	1.4733	.82741	50
11	184	917	.4724	724	49
12	208	.67960	.4715	708	48
13	232	.68002	.4705	692	47
14	256	045	.4696	675	46
15	.56280	.68088	1.4687	.82659	45
16	305	130	.4678	643	44
17	329	173	.4669	626	43
18	353	215	.4659	610	42
19	377	258	.4650	593	41
20	.56401	.68301	1.4641	.82577	40
21	425	343	.4632	561	39
22	449	386	.4623	544	38
23	473	429	.4614	528	37
24	497	471	.4605	511	36
25	.56521	.68514	1.4596	.82495	35
26	545	557	.4586	478	34
27	569	600	.4577	462	33
28	593	642	.4568	446	32
29	617	685	.4559	429	31
30	.56641	.68728	1.4550	.82413	30
31	665	771	.4541	396	29
32	689	814	.4532	380	28
33	713	857	.4523	363	27
34	736	900	.4514	347	26
35	.56760	.68942	1.4505	.82330	25
36	784	.68985	.4496	314	24
37	808	.69028	.4487	297	23
38	832	071	.4478	281	22
39	856	114	.4469	264	21
40	.56880	.69157	1.4460	.82248	20
41	904	200	.4451	231	19
42	928	243	.4442	214	18
43	952	286	.4433	198	17
44	.56976	329	.4424	181	16
45	.57000	.69372	1.4415	.82165	15
46	024	416	.4406	148	14
47	047	459	.4397	132	13
48	071	502	.4388	115	12
49	095	545	.4379	098	11
50	.57119	.69588	1.4370	.82082	10
51	143	631	.4361	065	9
52	167	675	.4352	048	8
53	191	718	.4344	032	7
54	215	761	.4335	.82015	6
55	57238	.69804	1.4326	.81999	5
56	262	847	.4317	982	4
57	286	891	.4308	965	3
58	310	934	.4299	949	2
59	334	.69977	.4290	932	1
60	.57358	.70021	1.4281	.81915	0
	cos	cot	tan	sin	′

145° 235° 325° **55°**

′	sin	tan	cot	cos	
0	.57358	.70021	1.4281	.81915	60
1	381	064	.4273	899	59
2	405	107	.4264	882	58
3	429	151	.4255	865	57
4	453	194	.4246	848	56
5	.57477	.70238	1.4237	.81832	55
6	501	281	.4229	815	54
7	524	325	.4220	798	53
8	548	368	.4211	782	52
9	572	412	.4202	765	51
10	.57596	.70455	1.4193	.81748	50
11	619	499	.4185	731	49
12	643	542	.4176	714	48
13	667	586	.4167	698	47
14	691	629	.4158	681	46
15	.57715	.70673	1.4150	.81664	45
16	738	717	.4141	647	44
17	762	760	.4132	631	43
18	786	804	.4124	614	42
19	810	848	.4115	597	41
20	.57833	.70891	1.4106	.81580	40
21	857	935	.4097	563	39
22	881	.70979	.4089	546	38
23	904	.71023	.4080	530	37
24	928	066	.4071	513	36
25	.57952	.71110	1.4063	.81496	35
26	976	154	.4054	479	34
27	.57999	198	.4045	462	33
28	.58023	242	.4037	445	32
29	047	285	.4028	428	31
30	.58070	.71329	1.4019	.81412	30
31	094	373	.4011	395	29
32	118	417	.4002	378	28
33	141	461	.3994	361	27
34	165	505	.3985	344	26
35	.58189	.71549	1.3976	.81327	25
36	212	593	.3968	310	24
37	236	637	.3959	293	23
38	260	681	.3951	276	22
39	283	725	.3942	259	21
40	.58307	.71769	1.3934	.81242	20
41	330	813	.3925	225	19
42	354	857	.3916	208	18
43	378	901	3908	191	17
44	401	946	.3899	174	16
45	.58425	.71990	1.3891	.81157	15
46	449	.72034	.3882	140	14
47	472	078	.3874	123	13
48	496	122	3865	106	12
49	519	167	.3857	089	11
50	.58543	.72211	1.3848	.81072	10
51	567	255	.3840	055	9
52	590	299	3831	038	8
53	614	344	.3823	021	7
54	637	388	3814	.81004	6
55	.58661	.72432	1.3806	80987	5
56	684	477	.3798	970	4
57	708	521	.3789	953	3
58	731	565	.3781	936	2
59	755	610	.3772	919	1
60	.58779	.72654	1.3764	.80902	0
	cos	cot	tan	sin	′

54° 144° 234° 324°

′	sin	tan	cot	cos	
0	.58779	.72654	1.3764	.80902	60
1	802	699	.3755	885	59
2	826	743	.3747	867	58
3	849	788	.3739	850	57
4	873	832	.3730	833	56
5	.58896	.72877	1.3722	.80816	55
6	920	921	.3713	799	54
7	943	.72966	.3705	782	53
8	967	.73010	.3697	765	52
9	.58990	055	.3688	748	51
10	.59014	.73100	1.3680	.80730	50
11	037	144	.3672	713	49
12	061	189	.3663	696	48
13	084	234	.3655	679	47
14	108	278	.3647	662	46
15	.59131	.73323	1.3638	.80644	45
16	154	368	.3630	627	44
17	178	413	.3622	610	43
18	201	457	.3613	593	42
19	225	502	.3605	576	41
20	.59248	.73547	1.3597	.80558	40
21	272	592	.3588	541	39
22	295	637	.3580	524	38
23	318	681	.3572	507	37
24	342	726	.3564	489	36
25	.59365	.73771	1.3555	.80472	35
26	389	816	.3547	455	34
27	412	861	.3539	438	33
28	436	906	.3531	420	32
29	459	951	.3522	403	31
30	.59482	.73996	1.3514	.80386	30
31	506	74041	.3506	368	29
32	529	086	.3498	351	28
33	552	131	.3490	334	27
34	576	176	.3481	316	26
35	.59599	.74221	1.3473	.80299	25
36	622	267	.3465	282	24
37	646	312	.3457	264	23
38	669	357	.3449	247	22
39	693	402	.3440	230	21
40	.59716	.74447	1.3432	.80212	20
41	739	492	3424	195	19
42	763	538	.3416	178	18
43	786	583	.3408	160	17
44	809	628	.3400	143	16
45	.59832	.74674	1.3392	.80125	15
46	856	719	.3384	108	14
47	879	764	.3375	091	13
48	902	810	.3367	073	12
49	926	855	.3359	056	11
50	.59949	.74900	1.3351	.80038	10
51	972	946	.3343	021	9
52	.59995	.74991	.3335	.80003	8
53	.60019	.75037	.3327	.79986	7
54	042	082	.3319	968	6
55	.60065	.75128	1.3311	.79951	5
56	089	173	.3303	934	4
57	112	219	.3295	916	3
58	135	264	.3287	899	2
59	158	310	.3278	881	1
60	.60182	.75355	1.3270	.79864	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.60182	.75355	1.3270	.79864	60
1	205	401	.3262	846	59
2	228	447	.3254	829	58
3	251	492	.3246	811	57
4	274	538	.3238	793	56
5	.60298	.75584	1.3230	.79776	55
6	321	629	.3222	758	54
7	344	675	.3214	741	53
8	367	721	.3206	723	52
9	390	767	.3198	706	51
10	.60414	.75812	1.3190	.79688	50
11	437	858	.3182	671	49
12	460	904	.3175	653	48
13	483	950	.3167	635	47
14	506	.75996	.3159	618	46
15	.60529	.76042	1.3151	.79600	45
16	553	088	.3143	583	44
17	576	134	.3135	565	43
18	599	180	.3127	547	42
19	622	226	.3119	530	41
20	.60645	.76272	1.3111	.79512	40
21	668	318	.3103	494	39
22	691	364	.3095	477	38
23	714	410	.3087	459	37
24	738	456	.3079	441	36
25	.60761	.76502	1.3072	.79424	35
26	784	548	.3064	406	34
27	807	594	.3056	388	33
28	830	640	.3048	371	32
29	853	686	.3040	353	31
30	.60876	.76733	1.3032	.79335	30
31	899	779	.3024	318	29
32	922	825	.3017	300	28
33	945	871	.3009	282	27
34	968	918	.3001	264	26
35	.60991	.76964	1.2993	.79247	25
36	.61015	.77010	.2985	229	24
37	038	057	.2977	211	23
38	061	103	.2970	193	22
39	084	149	.2962	176	21
40	.61107	.77196	1.2954	.79158	20
41	130	242	.2946	140	19
42	153	289	.2938	122	18
43	176	335	.2931	105	17
44	199	382	.2923	087	16
45	.61222	.77428	1.2915	.79069	15
46	245	475	.2907	051	14
47	268	521	.2900	033	13
48	291	568	.2892	.79016	12
49	314	615	.2884	.78998	11
50	.61337	.77661	1.2876	.78980	10
51	360	708	.2869	962	9
52	383	754	.2861	944	8
53	406	801	.2853	926	7
54	429	848	.2846	908	6
55	.61451	.77895	1.2838	.78891	5
56	474	941	.2830	873	4
57	497	.77988	.2822	855	3
58	520	.78035	.2815	837	2
59	543	082	.2807	819	1
60	.61566	.78129	1.2799	.78801	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.61566	.78129	1.2799	.78801	60
1	589	175	.2792	783	59
2	612	222	.2784	765	58
3	635	269	.2776	747	57
4	658	316	.2769	729	56
5	.61681	.78363	1.2761	.78711	55
6	704	410	.2753	694	54
7	726	457	.2746	676	53
8	749	504	.2738	658	52
9	772	551	.2731	640	51
10	.61795	.78598	1.2723	.78622	50
11	818	645	.2715	604	49
12	841	692	.2708	586	48
13	864	739	.2700	568	47
14	887	786	.2693	550	46
15	.61909	.78834	1.2685	.78532	45
16	932	881	.2677	514	44
17	955	928	.2670	496	43
18	.61978	.78975	.2662	478	42
19	.62001	.79022	.2655	460	41
20	.62024	.79070	1.2647	.78442	40
21	046	117	.2640	424	39
22	069	164	.2632	405	38
23	092	212	.2624	387	37
24	115	259	.2617	369	36
25	.62138	.79306	1.2609	.78351	35
26	160	354	.2602	333	34
27	183	401	.2594	315	33
28	206	449	.2587	297	32
29	229	496	.2579	279	31
30	.62251	.79544	1.2572	.78261	30
31	274	591	.2564	243	29
32	297	639	.2557	225	28
33	320	686	.2549	206	27
34	342	734	.2542	188	26
35	.62365	.79781	1.2534	.78170	25
36	388	829	.2527	152	24
37	411	877	.2519	134	23
38	433	924	.2512	116	22
39	456	.79972	.2504	098	21
40	.62479	.80020	1.2497	.78079	20
41	502	067	.2489	061	19
42	524	115	.2482	043	18
43	547	163	.2475	025	17
44	570	211	.2467	.78007	16
45	.62592	.80258	1.2460	.77988	15
46	615	306	.2452	970	14
47	638	354	.2445	952	13
48	660	402	.2437	934	12
49	683	450	.2430	916	11
50	.62706	.80498	1.2423	.77897	10
51	728	546	.2415	879	9
52	751	594	.2408	861	8
53	774	642	.2401	843	7
54	796	690	.2393	824	6
55	.62819	.80738	1.2386	.77806	5
56	842	786	.2378	788	4
57	864	834	.2371	769	3
58	887	882	.2364	751	2
59	909	930	.2356	733	1
60	.62932	.80978	1.2349	.77715	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.62932	.80978	1.2349	.77715	60
1	955	.81027	.2342	696	59
2	.62977	075	.2334	678	58
3	.63000	123	.2327	660	57
4	022	171	.2320	641	56
5	.63045	.81220	1.2312	.77623	55
6	068	268	.2305	605	54
7	090	316	.2298	586	53
8	113	364	.2290	568	52
9	135	413	.2283	550	51
10	.63158	.81461	1.2276	.77531	50
11	180	510	.2268	513	49
12	203	558	.2261	494	48
13	225	606	.2254	476	47
14	248	655	.2247	458	46
15	.63271	.81703	1.2239	.77439	45
16	293	752	.2232	421	44
17	316	800	.2225	402	43
18	338	849	.2218	384	42
19	361	898	.2210	366	41
20	.63383	.81946	1.2203	.77347	40
21	406	.81995	.2196	329	39
22	428	.82044	.2189	310	38
23	451	092	.2181	292	37
24	473	141	.2174	273	36
25	.63496	.82190	1.2167	.77255	35
26	518	238	.2160	236	34
27	540	287	.2153	218	33
28	563	336	.2145	199	32
29	585	385	.2138	181	31
30	.63608	.82434	1.2131	.77162	30
31	630	483	.2124	144	29
32	653	531	.2117	125	28
33	675	580	.2109	107	27
34	698	629	.2102	088	26
35	.63720	.82678	1.2095	.77070	25
36	742	727	.2088	051	24
37	765	776	.2081	033	23
38	787	825	.2074	.77014	22
39	810	874	.2066	.76996	21
40	.63832	.82923	1.2059	.76977	20
41	854	.82972	.2052	959	19
42	877	.83022	.2045	940	18
43	899	071	.2038	921	17
44	922	120	.2031	903	16
45	.63944	.83169	1.2024	.76884	15
46	966	218	.2017	866	14
47	.63989	268	.2009	847	13
48	.64011	317	.2002	828	12
49	033	366	.1995	810	11
50	.64056	.83415	1.1988	.76791	10
51	078	465	.1981	772	9
52	100	514	.1974	754	8
53	123	564	.1967	735	7
54	145	613	.1960	717	6
55	.64167	.83662	1.1953	.76698	5
56	190	712	.1946	679	4
57	212	761	.1939	661	3
58	234	811	.1932	642	2
59	256	860	.1925	623	1
60	.64279	.83910	1.1918	.76604	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.64279	.83910	1.1918	.76604	60
1	301	.83960	.1910	586	59
2	323	.84009	.1903	567	58
3	346	059	.1896	548	57
4	368	108	.1889	530	56
5	.64390	.84158	1.1882	.76511	55
6	412	208	.1875	492	54
7	435	258	.1868	473	53
8	457	307	.1861	455	52
9	479	357	.1854	436	51
10	.64501	.84407	1.1847	.76417	50
11	524	457	.1840	398	49
12	546	507	.1833	380	48
13	568	556	.1826	361	47
14	590	606	.1819	342	46
15	.64612	.84656	1.1812	.76323	45
16	635	706	.1806	304	44
17	657	756	.1799	286	43
18	679	806	.1792	267	42
19	701	856	.1785	248	41
20	.64723	.84906	1.1778	.76229	40
21	746	.84956	.1771	210	39
22	768	.85006	.1764	192	38
23	790	057	.1757	173	37
24	812	107	.1750	154	36
25	.64834	.85157	1.1743	.76135	35
26	856	207	.1736	116	34
27	878	257	.1729	097	33
28	901	308	.1722	078	32
29	923	358	.1715	059	31
30	.64945	.85408	1.1708	.76041	30
31	967	458	.1702	022	29
32	.64989	509	.1695	.76003	28
33	.65011	559	.1688	.75984	27
34	033	609	.1681	965	26
35	.65055	.85660	1.1674	.75946	25
36	077	710	.1667	927	24
37	100	761	.1660	908	23
38	122	811	.1653	889	22
39	144	862	.1647	870	21
40	65166	.85912	1.1640	.75851	20
41	188	.85963	.1633	832	19
42	210	.86014	.1626	813	18
43	232	064	.1619	794	17
44	254	115	.1612	775	16
45	.65276	.86166	1.1606	.75756	15
46	298	216	.1599	738	14
47	320	267	.1592	719	13
48	342	318	.1585	700	12
49	364	368	.1578	680	11
50	.65386	.86419	1.1571	.75661	10
51	408	470	.1565	642	9
52	430	521	.1558	623	8
53	452	572	.1551	604	7
54	474	623	.1544	585	6
55	.65496	.86674	1.1538	.75566	5
56	518	725	.1531	547	4
57	540	776	.1524	528	3
58	562	827	.1517	509	2
59	584	878	.1510	490	1
60	.65606	.86929	1.1504	.75471	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.65606	.86929	1.1504	.75471	60
1	628	.86980	.1497	452	59
2	650	.87031	.1490	433	58
3	672	082	.1483	414	57
4	694	133	.1477	395	56
5	.65716	.87184	1.1470	.75375	55
6	738	236	.1463	356	54
7	759	287	.1456	337	53
8	781	338	.1450	318	52
9	803	389	.1443	299	51
10	.65825	.87441	1.1436	.75280	50
11	847	492	.1430	261	49
12	869	543	.1423	241	48
13	891	595	.1416	222	47
14	913	646	.1410	203	46
15	.65935	.87698	1.1403	.75184	45
16	956	749	.1396	165	44
17	.65978	801	.1389	146	43
18	.66000	852	.1383	126	42
19	022	904	.1376	107	41
20	.66044	.87955	1.1369	.75088	40
21	066	.88007	.1363	069	39
22	088	059	.1356	050	38
23	109	110	.1349	030	37
24	131	162	.1343	.75011	36
25	.66153	.88214	1.1336	.74992	35
26	175	265	.1329	973	34
27	197	317	.1323	953	33
28	218	369	.1316	934	32
29	240	421	.1310	915	31
30	.66262	.88473	1.1303	.74896	30
31	284	524	.1296	876	29
32	306	576	.1290	857	28
33	327	628	.1283	838	27
34	349	680	.1276	818	26
35	.66371	.88732	1.1270	.74799	25
36	393	784	.1263	780	24
37	414	836	.1257	760	23
38	436	888	.1250	741	22
39	458	940	.1243	722	21
40	.66480	.88992	1.1237	.74703	20
41	501	.89045	.1230	683	19
42	523	097	.1224	664	18
43	545	149	.1217	644	17
44	566	201	.1211	625	16
45	.66588	.89253	1.1204	.74606	15
46	610	306	.1197	586	14
47	632	358	.1191	567	13
48	653	410	.1184	548	12
49	675	463	.1178	528	11
50	.66697	.89515	1.1171	.74509	10
51	718	567	.1165	489	9
52	740	620	.1158	470	8
53	762	672	.1152	451	7
54	783	725	.1145	431	6
55	.66805	.89777	1.1139	.74412	5
56	827	830	.1132	392	4
57	848	883	.1126	373	3
58	870	935	.1119	353	2
59	891	.89988	.1113	334	1
60	.66913	.90040	1.1106	.74314	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.66913	.90040	1.1106	.74314	60
1	935	093	.1100	295	59
2	956	146	.1093	276	58
3	978	199	.1087	256	57
4	.66999	251	.1080	237	56
5	.67021	.90304	1.1074	.74217	55
6	043	357	.1067	198	54
7	064	410	.1061	178	53
8	086	463	.1054	159	52
9	107	516	.1048	139	51
10	.67129	.90569	1.1041	.74120	50
11	151	621	.1035	100	49
12	172	674	.1028	080	48
13	194	727	.1022	061	47
14	215	781	.1016	041	46
15	.67237	.90834	1.1009	.74022	45
16	258	887	.1003	.74002	44
17	280	940	.0996	.73983	43
18	301	.90993	.0990	963	42
19	323	.91046	.0983	944	41
20	.67344	.91099	1.0977	.73924	40
21	366	153	.0971	904	39
22	387	206	.0964	885	38
23	409	259	.0958	865	37
24	430	313	.0951	846	36
25	.67452	.91366	1.0945	.73826	35
26	473	419	.0939	806	34
27	495	473	.0932	787	33
28	516	526	.0926	767	32
29	538	580	.0919	747	31
30	.67559	.91633	1.0913	.73728	30
31	580	687	.0907	708	29
32	602	740	.0900	688	28
33	623	794	.0894	669	27
34	645	847	.0888	649	26
35	.67666	.91901	1.0881	.73629	25
36	688	.91955	.0875	610	24
37	709	.92008	.0869	590	23
38	730	062	.0862	570	22
39	752	116	.0856	551	21
40	.67773	.92170	1.0850	.73531	20
41	795	224	.0843	511	19
42	816	277	.0837	491	18
43	837	331	.0831	472	17
44	859	385	.0824	452	16
45	.67880	.92439	1.0818	.73432	15
46	901	493	.0812	413	14
47	923	547	.0805	393	13
48	944	601	.0799	373	12
49	965	655	.0793	353	11
50	.67987	.92709	1.0786	.73333	10
51	.68008	763	.0780	314	9
52	029	817	.0774	294	8
53	051	872	.0768	274	7
54	072	926	.0761	254	6
55	.68093	.92980	1.0755	.73234	5
56	115	.93034	.0749	215	4
57	136	088	.0742	195	3
58	157	143	.0736	175	2
59	179	197	.0730	155	1
60	.68200	.93252	1.0724	.73135	0
	cos	cot	tan	sin	′

′	sin	tan	cot	cos	
0	.68200	.93252	1.0724	.73135	60
1	221	306	.0717	116	59
2	242	360	.0711	096	58
3	264	415	.0705	076	57
4	285	469	.0699	056	56
5	.68306	.93524	1.0692	.73036	55
6	327	578	.0686	.73016	54
7	349	633	.0680	.72996	53
8	370	688	.0674	976	52
9	391	742	.0668	957	51
10	.68412	.93797	1.0661	.72937	50
11	434	852	.0655	917	49
12	455	906	.0649	897	48
13	476	.93961	.0643	877	47
14	497	.94016	.0637	857	46
15	.68518	.94071	1.0630	.72837	45
16	539	125	.0624	817	44
17	561	180	.0618	797	43
18	582	235	.0612	777	42
19	603	290	.0606	757	41
20	.68624	.94345	1.0599	.72737	40
21	645	400	.0593	717	39
22	666	455	.0587	697	38
23	688	510	.0581	677	37
24	709	565	.0575	657	36
25	.68730	.94620	1.0569	.72637	35
26	751	676	.0562	617	34
27	772	731	.0556	597	33
28	793	786	.0550	577	32
29	814	841	.0544	557	31
30	.68835	.94896	1.0538	.72537	30
31	857	.94952	.0532	517	29
32	878	.95007	.0526	497	28
33	899	062	.0519	477	27
34	920	118	.0513	457	26
35	.68941	.95173	1.0507	.72437	25
36	962	229	.0501	417	24
37	.68983	284	.0495	397	23
38	.69004	340	.0489	377	22
39	025	395	.0483	357	21
40	.69046	.95451	1.0477	.72337	20
41	067	506	.0470	317	19
42	088	562	.0464	297	18
43	109	618	.0458	277	17
44	130	673	.0452	257	16
45	.69151	.95729	1.0446	.72236	15
46	172	785	.0440	216	14
47	193	841	.0434	196	13
48	214	897	.0428	176	12
49	235	.95952	.0422	156	11
50	.69256	.96008	1.0416	.72136	10
51	277	064	.0410	116	9
52	298	120	.0404	095	8
53	319	176	.0398	075	7
54	340	232	.0392	055	6
55	.69361	.96288	1.0385	.72035	5
56	382	344	.0379	.72015	4
57	403	400	.0373	.71995	3
58	424	457	.0367	974	2
59	445	513	.0361	954	1
60	.69466	.96569	1.0355	.71934	0
	cos	cot	tan	sin	′

44° 134° 224° 314°

′	sin	tan	cot	cos	′
0	.69466	.96569	1.0355	.71934	60
1	487	625	.0349	914	59
2	508	681	.0343	894	58
3	529	738	.0337	873	57
4	549	794	.0331	853	56
5	.69570	.96850	1.0325	.71833	55
6	591	907	.0319	813	54
7	612	.96963	.0313	792	53
8	633	.97020	.0307	772	52
9	654	076	.0301	752	51
10	.69675	.97133	1.0295	.71732	50
11	696	189	.0289	711	49
12	717	246	.0283	691	48
13	737	302	.0277	671	47
14	758	359	.0271	650	46
15	.69779	.97416	1.0265	.71630	45
16	800	472	.0259	610	44
17	821	529	.0253	590	43
18	842	586	.0247	569	42
19	862	643	.0241	549	41
20	.69883	.97700	1.0235	.71529	40
21	904	756	.0230	508	39
22	925	813	.0224	488	38
23	946	870	.0218	468	37
24	966	927	.0212	447	36
25	.69987	.97984	1.0206	.71427	35
26	.70008	.98041	.0200	407	34
27	029	098	.0194	386	33
28	049	155	.0188	366	32
29	070	213	.0182	345	31
30	.70091	.98270	1.0176	.71325	30
31	112	327	.0170	305	29
32	132	384	.0164	284	28
33	153	441	.0158	264	27
34	174	499	.0152	243	26
35	.70195	.98556	1.0147	.71223	25
36	215	613	.0141	203	24
37	236	671	.0135	182	23
38	257	728	.0129	162	22
39	277	786	.0123	141	21
40	.70298	.98843	1.0117	.71121	20
41	319	901	.0111	100	19
42	339	.98958	.0105	080	18
43	360	.99016	.0099	059	17
44	381	073	.0094	039	16
45	.70401	.99131	1.0088	.71019	15
46	422	189	.0082	.70998	14
47	443	247	.0076	978	13
48	463	304	.0070	957	12
49	484	362	.0064	937	11
50	.70505	.99420	1.0058	.70916	10
51	525	478	.0052	896	9
52	546	536	.0047	875	8
53	567	594	.0041	855	7
54	587	652	.0035	834	6
55	.70608	.99710	1.0029	.70813	5
56	628	768	.0023	793	4
57	649	826	.0017	772	3
58	670	884	.0012	752	2
59	690	.99942	.0006	731	1
60	.70711	1.0000	1.0000	.70711	0
	cos	cot	tan	sin	

45° 135° 225° 315°

Table II.—Reductions of Stadia Observations for Rod Readings of 100

(General Land Office, Washington, D. C.)

Minutes	0°		1°		2°		3°		4°	
	Dist.	Elev.	Dist.	Elev.	Dist.	Elev.	Dist.	Elev.	Dist.	Elev.
0′	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28	99.51	7.02
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34	99.50	7.07
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40	99.49	7.13
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46	99.48	7.19
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52	99.47	7.25
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57	99.46	7.30
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63	99.46	7.36
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69	99.45	7.42
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75	99.44	7.48
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80	99.43	7.53
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86	99.42	7.59
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92	99.41	7.65
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98	99.40	7.71
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04	99.39	7.76
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09	99.38	7.82
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15	99.38	7.88
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21	99.37	7.94
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27	99.36	7.99
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33	99.35	8.05
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38	99.34	8.11
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44	99.33	8.17
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50	99.32	8.22
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56	99.31	8.28
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61	99.30	8.34
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67	99.29	8.40
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73	99.28	8.45
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78	99.27	8.51
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84	99.26	8.57
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90	99.25	8.63
$c + f = 0.75$	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05	0.75	0.06
$c + f = 1.00$	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06	1.00	0.08
$c + f = 1.25$	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08	1.25	0.10

Minutes	5°		6°		7°		8°		9°	
0′	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78	97.55	15.45
2	99.23	8.74	98.90	10.45	98.50	12.15	98.05	13.84	97.53	15.51
4	99.22	8.80	98.88	10.51	98.48	12.21	98.03	13.89	97.52	15.56
6	99.21	8.85	98.87	10.57	98.47	12.26	98.01	13.95	97.50	15.62
8	99.20	8.91	98.86	10.62	98.46	12.32	98.00	14.01	97.48	15.67
10	99.19	8.97	98.85	10.68	98.44	12.38	97.98	14.06	97.46	15.73
12	99.18	9.03	98.83	10.74	98.43	12.43	97.97	14.12	97.44	15.78
14	99.17	9.08	98.82	10.79	98.41	12.49	97.95	14.17	97.43	15.84
16	99.16	9.14	98.81	10.85	98.40	12.55	97.93	14.23	97.41	15.89
18	99.15	9.20	98.80	10.91	98.39	12.60	97.92	14.28	97.39	15.95
20	99.14	9.25	98.78	10.96	98.37	12.66	97.90	14.34	97.37	16.00
22	99.13	9.31	98.77	11.02	98.36	12.72	97.88	14.40	97.35	16.06
24	99.11	9.37	98.76	11.08	98.34	12.77	97.87	14.45	97.33	16.11
26	99.10	9.43	98.74	11.13	98.33	12.83	97.85	14.51	97.31	16.17
28	99.09	9.48	98.73	11.19	98.31	12.88	97.83	14.56	97.29	16.22
30	99.08	9.54	98.72	11.25	98.29	12.94	97.82	14.62	97.28	16.28
32	99.07	9.60	98.71	11.30	98.28	13.00	97.80	14.67	97.26	16.33
34	99.06	9.65	98.69	11.36	98.27	13.05	97.78	14.73	97.24	16.39
36	99.05	9.71	98.68	11.42	98.25	13.11	97.76	14.79	97.22	16.44
38	99.04	9.77	98.67	11.47	98.24	13.17	97.75	14.84	97.20	16.50
40	99.03	9.83	98.65	11.53	98.22	13.22	97.73	14.90	97.18	16.55
42	99.01	9.88	98.64	11.59	98.20	13.28	97.71	14.95	97.16	16.61
44	99.00	9.94	98.63	11.64	98.19	13.33	97.69	15.01	97.14	16.66
46	98.99	10.00	98.61	11.70	98.17	13.39	97.68	15.06	97.12	16.72
48	98.98	10.05	98.60	11.76	98.16	13.45	97.66	15.12	97.10	16.77
50	98.97	10.11	98.58	11.81	98.14	13.50	97.64	15.17	97.08	16.83
52	98.96	10.17	98.57	11.87	98.13	13.56	97.62	15.23	97.06	16.88
54	98.94	10.22	98.56	11.93	98.11	13.61	97.61	15.28	97.04	16.94
56	98.93	10.28	98.54	11.98	98.10	13.67	97.59	15.34	97.02	16.99
58	98.92	10.34	98.53	12.04	98.08	13.73	97.57	15.40	97.00	17.05
$c + f = 0.75$	0.75	0.07	0.75	0.08	0.74	0.10	0.74	0.11	0.74	0.12
$c + f = 1.00$	0.99	0.09	0.99	0.11	0.99	0.13	0.99	0.15	0.99	0.16
$c + f = 1.25$	1.24	0.11	1.24	0.14	1.24	0.16	1.23	0.18	1.23	0.21

Table II.—(*Continued*)

Minutes	10°		11°		12°		13°		14°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff Elev
0′	96.98	17.10	96.36	18.73	95.68	20.34	94.94	21.92	94.15	23.47
2	96.96	17.16	96.34	18.78	96.65	20.39	94.91	21.97	94.12	23.52
4	96.94	17.21	96.32	18.84	95.63	20.44	94.89	22.02	94.09	23.58
6	96.92	17.26	96.29	18.89	95.61	20.50	94.86	22.08	94.07	23.63
8	96.90	17.32	96.27	18.95	95.58	20.55	94.84	22.13	94.04	23.68
10	96.88	17.37	96.25	19.00	95.56	20.60	94.81	22.18	94.01	23.73
12	96.86	17.43	96.23	19.05	95.53	20.66	94.79	22.23	93.98	23.78
14	96.84	17.48	96.21	19.11	95.51	20.71	94.76	22.28	93.95	23.83
16	96.82	17.54	96.18	19.16	95.49	20.76	94.73	22.34	93.93	23.88
18	96.80	17.59	96.16	19.21	95.46	20.81	94.71	22.39	93.90	23.93
20	96.78	17.65	96.14	19.27	95.44	20.87	94.68	22.44	93.87	23.99
22	96.76	17.70	96.12	19.32	95.41	20.92	94.66	22.49	93.84	24.04
24	96.74	17.76	96.09	19.38	95.39	20.97	94.63	22.54	93.81	24.09
26	96.72	17.81	96.07	19.43	95.36	21.03	94.60	22.60	93.79	24.14
28	96.70	17.86	96.05	19.48	95.34	21.08	94.58	22.65	93.76	24.19
30	96.68	17.92	96.03	19.54	95.32	21.13	94.55	22.70	93.73	24.24
32	96.66	17.97	96.00	19.59	95.29	21.18	94.52	22.75	93.70	24.29
34	96.64	18.03	95.98	19.64	95.27	21.24	94.50	22.80	93.67	24.34
36	96.62	18.08	95.96	19.70	95.24	21.29	94.47	22.85	93.65	24.39
38	96.60	18.14	95.93	19.75	95.22	21.34	94.44	22.91	93.62	24.44
40	96.57	18.19	95.91	19.80	95.19	21.39	94.42	22.96	93.59	24.49
42	96.55	18.24	95.89	19.86	95.17	21.45	94.39	23.01	93.56	24.55
44	96.53	18.30	95.86	19.91	95.14	21.50	94.36	23.06	93.53	24.60
46	96.51	18.35	95.84	19.96	95.12	21.55	94.34	23.11	93.50	24.65
48	96.49	18.41	95.82	20.02	95.09	21.60	94.31	23.16	93.47	24.70
50	96.47	18.46	95.79	20.07	95.07	21.66	94.28	23.22	93.45	24.75
52	96.45	18.51	95.77	20.12	95.04	21.71	94.26	23.27	93.42	24.80
54	96.42	18.57	95.75	20.18	95.02	21.76	94.23	23.32	93.39	24.85
56	96.40	18.62	95.72	20.23	94.99	21.81	94.20	23.37	93.36	24.90
58	96.38	18.68	95.70	20.28	94.97	21.87	94.17	23.42	93.33	24.95
$c + f = 0.75$	0.74	0.14	0.73	0.15	0.73	0.16	0.73	0.17	0.73	0.19
$c + f = 1.00$	0.98	0.18	0.98	0.20	0.98	0.22	0.97	0.23	0.97	0.25
$c + f = 1.25$	1.23	0.23	1.22	0.25	1.22	0.27	1.21	0.29	1.21	0.31

Minutes	15°		16°		17°		18°		19°	
0′	93.30	25.00	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2	93.27	25.05	92.37	26.55	91.42	28.01	90.42	29.44	80.36	30.83
4	93.24	25.10	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6	93.21	25.15	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92
8	93.18	25.20	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10	93.16	25.25	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01
12	93.13	25.30	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06
14	93.10	25.35	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10
16	93.07	25.40	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18	93.04	25.45	92.12	26.94	91.16	28.39	90.14	28.81	89.08	31.19
20	93.01	25.50	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22	92.98	25.55	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24	92.95	25.60	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26	92.92	25.65	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38
28	92.89	25.70	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42
30	92.86	25.75	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32	92.83	25.80	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51
34	92.80	25.85	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36	92.77	25.90	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60
38	92.74	25.95	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40	92.71	26.00	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69
42	92.68	26.05	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44	92.65	26.10	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46	92.62	26.15	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83
48	92.59	26.20	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50	92.56	26.25	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52	92.53	26.30	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54	92.49	26.35	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56	92.46	26.40	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58	92.43	26.45	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09
$c + f = 0.75$	0.72	0.20	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25
$c + f = 1.00$	0.96	0.27	0.96	0.28	0.95	0.30	0.95	0.32	0.94	0.33
$c + f = 1.25$	1.20	0.34	1.20	0.36	1.19	0.38	1.19	0.40	1.18	0.42

Explanation of Table III

Stadia Tables for Obtaining Differences of Elevation

United States Geological Survey tables by C. G. Anderson.

"These tables are designed to serve the double purpose of obtaining accurate differences of elevation in traversing, by use of vertical angles and *observed* stadia distances, and of obtaining less accurate differences of elevation for topographic sketching away from the traverse line, where distances are determined by intersection upon the plane-table and measured in feet with the platting scale.

"*Explanation.*—The degrees of the vertical angles are printed in heavy type at the top of each page; the minutes in the right and left vertical columns. The figures in the top horizontal line represent the *observed* stadia distances in feet, read upon a rod held vertically. The numbers in the bottom horizontal line represent the correct horizontal distances, based on the middle (30′) angle of the page and corresponding to the observed stadia distance at the top of the same vertical column. The horizontal distances are also for use in platting. The numbers in the body of the table are differences of elevation in feet. Tabular values for the omitted columns, viz, 1000, 2000 and 3000, can be obtained from columns 100, 200, and 300, respectively, by moving the decimal point one place to the right; and for distances less than any of the even hundreds by moving it to the left.

"In stadia traversing for any vertical angle the argument for the difference of elevation is the *observed* stadia distance.

"Example: Required the difference of elevation for an angle of 3° 16′ for an observed stadia distance of 3645 ft. (See the 3° page of table.)

	Ft.
Difference of elevation for 3000 ft. (point moved to right)	170.7
Difference of elevation for 600 ft.	34.1
Difference of elevation for 40 ft. (point moved to left)	2.28
Difference of elevation for 5 feet (point moved two places to left) . .	.28
Adding gives *correct* difference of elevation required	207.3

"For topographic sketching of intersected points, the argument for the difference of elevation for any vertical angle is the *correct horizontal* distance

at the bottom of the page. If more refined results are required for intersected points, an interpolation of the horizontal distances may be made and a correction for curvature and refraction applied.

"*Theory.*—The formula $\text{Diff. Elev.} = \dfrac{\text{Observed distance} \times \text{sine 2 vert. angle}}{2}$ has been employed in the computation of these tables. Where more than ordinary accuracy is required in stadia measurements, a correction equal to the "stadia constant" (or $f + c$) times the sine of the vertical angle should be *added* to the values of the *difference of elevation* given in these tables. This correction may be obtained by double interpolation from the small table below, in which the arguments used are the stadia constant and the vertical angle.

Stadia constant (or f + c)	5°	10°	15°	20°	25°	30°
	Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
1.00 (ft)...............	0.09	0.17	0.26	0.34	0.42	0.50
1.25....................	0.11	0.22	0.37	0.43	0.53	0.62
1.50....................	0.13	0.26	0.41	0.51	0.62	0.75

"Example: Required correction to tabular difference of elevation when 'stadia constant' = 1.15 ft. and vertical angle = 21° 00′. By double interpolation the tabular value for this angle = 0.42 ft. Add this correction to the *difference* of elevation already found from the stadia tables.

"NOTE.—f = focal length of instrument, which is the distance from the objective lens to point in front where rays from distant object cross before entering the telescope. The focal length is equal to the distance from the objective lens to the cross hairs when the telescope is focused upon a distant object, and for any instrument should be actually measured. c = distance from objective lens to center of transverse axes when telescope is focused upon distant object."

Table III

0°

′	100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	1700
1	0.03	0.06	0.09	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5
2	0.06	0.12	0.17	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	0.9	1.0
3	0.09	0.18	0.26	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.0	1.1	1.2	1.3	1.4	1.5
4	0.12	0.23	0.35	0.4	0.6	0.7	0.8	0.9	1.0	1.3	1.4	1.5	1.6	1.7	1.9	2.0
5	0.15	0.29	0.44	0.6	0.7	0.9	1.0	1.2	1.3	1.6	1.7	1.9	2.0	2.2	2.3	2.5
6	0.18	0.35	0.52	0.7	0.9	1.0	1.2	1.4	1.6	1.9	2.1	2.3	2.4	2.6	2.8	3.0
7	0.20	0.41	0.61	0.8	1.0	1.2	1.4	1.6	1.8	2.2	2.4	2.6	2.8	3.0	3.3	3.5
8	0.23	0.46	0.70	0.9	1.2	1.4	1.6	1.9	2.1	2.6	2.8	3.0	3.3	3.5	3.7	4.0
9	0.26	0.52	0.79	1.0	1.3	1.6	1.8	2.1	2.4	2.9	3.1	3.4	3.7	3.9	4.2	4.4
10	0.29	0.58	0.87	1.2	1.5	1.7	2.0	2.3	2.6	3.2	3.5	3.8	4.1	4.4	4.7	4.9
11	0.32	0.64	0.96	1.3	1.6	1.9	2.2	2.6	2.9	3.5	3.8	4.2	4.5	4.8	5.1	5.4
12	0.35	0.70	1.05	1.4	1.7	2.1	2.4	2.8	3.1	3.8	4.2	4.5	4.9	5.2	5.6	5.9
13	0.38	0.77	1.13	1.5	1.9	2.3	2.6	3.0	3.4	4.2	4.5	4.9	5.3	5.7	6.0	6.4
14	0.41	0.81	1.22	1.6	2.0	2.4	2.8	3.3	3.7	4.5	4.9	5.3	5.7	6.1	6.5	6.9
15	0.44	0.87	1.31	1.7	2.2	2.6	3.1	3.5	3.9	4.8	5.2	5.7	6.1	6.5	7.0	7.4
16	0.47	0.93	1.40	1.9	2.3	2.8	3.3	3.7	4.2	5.1	5.6	6.0	6.5	7.0	7.4	7.9
17	0.49	0.99	1.48	2.0	2.5	3.0	3.5	4.0	4.4	5.4	5.9	6.4	6.9	7.4	7.9	8.4
18	0.52	1.05	1.57	2.1	2.6	3.1	3.7	4.2	4.7	5.8	6.3	6.8	7.3	7.8	8.4	8.9
19	0.55	1.10	1.66	2.2	2.8	3.3	3.9	4.4	4.9	6.1	6.6	7.2	7.7	8.3	8.8	9.4
20	0.58	1.16	1.75	2.3	2.9	3.5	4.1	4.7	5.2	6.4	7.0	7.6	8.1	8.7	9.3	10.0
21	0.61	1.22	1.83	2.4	3.1	3.7	4.3	4.9	5.5	6.7	7.3	7.9	8.6	9.2	9.8	10.4
22	0.64	1.28	1.92	2.6	3.2	3.8	4.5	5.1	5.8	7.0	7.7	8.3	9.0	9.6	10.2	10.9
23	0.67	1.34	2.01	2.7	3.3	4.0	4.7	5.4	6.0	7.4	8.0	8.7	9.4	10.0	10.7	11.4
24	0.70	1.40	2.09	2.8	3.5	4.2	4.9	5.6	6.3	7.7	8.4	9.1	9.8	10.5	11.2	11.9
25	0.73	1.45	2.18	2.9	3.6	4.4	5.1	5.8	6.5	8.0	8.7	9.4	10.2	10.9	11.6	12.4
26	0.76	1.51	2.27	3.0	3.8	4.5	5.3	6.0	6.8	8.3	9.1	9.8	10.6	11.3	12.1	12.9
27	0.79	1.57	2.36	3.1	3.9	4.7	5.5	6.3	7.1	8.6	9.4	10.2	11.0	11.8	12.6	13.3
28	0.81	1.63	2.44	3.3	4.1	4.9	5.7	6.5	7.3	9.0	9.8	10.6	11.4	12.2	13.0	13.8
29	0.84	1.69	2.53	3.4	4.2	5.1	5.9	6.7	7.6	9.3	10.1	11.1	11.8	12.6	13.5	14.3
30	0.87	1.74	2.62	3.5	4.4	5.2	6.1	7.0	7.8	9.6	10.5	11.3	12.2	13.1	14.0	14.8
31	0.90	1.80	2.70	3.6	4.5	5.4	6.3	7.2	8.1	9.9	10.8	11.7	12.6	13.5	14.4	15.3
32	0.93	1.86	2.79	3.7	4.7	5.6	6.5	7.4	8.4	10.2	11.2	12.1	13.0	14.0	14.9	15.8
33	0.96	1.92	2.88	3.8	4.8	5.8	6.7	7.7	8.6	10.6	11.5	12.5	13.4	14.4	15.4	16.3
34	0.99	1.98	2.97	4.0	4.9	5.9	6.9	7.9	8.9	10.9	11.9	12.9	13.8	14.8	15.8	16.8
35	1.02	2.04	3.05	4.1	5.1	6.1	7.1	8.1	9.2	11.2	12.2	13.2	14.2	15.3	16.3	17.3
36	1.05	2.09	3.14	4.2	5.2	6.3	7.3	8.4	9.4	11.5	12.6	13.6	14.7	15.7	16.7	17.8
37	1.08	2.15	3.23	4.3	5.4	6.5	7.5	8.6	9.7	11.8	12.9	14.0	15.1	16.1	17.2	18.3
38	1.11	2.21	3.32	4.4	5.5	6.6	7.7	8.8	9.9	12.2	13.3	14.4	15.5	16.6	17.7	18.8
39	1.13	2.27	3.40	4.5	5.7	6.8	8.0	9.1	10.2	12.5	13.6	14.7	15.9	17.0	18.2	19.3
40	1.16	2.33	3.49	4.7	5.8	7.0	8.1	9.3	10.5	12.8	14.0	15.1	16.3	17.4	18.6	19.8
41	1.19	2.38	3.58	4.8	6.0	7.2	8.3	9.5	10.7	13.1	14.3	15.5	16.7	17.9	19.1	20.3
42	1.22	2.44	3.66	4.9	6.1	7.3	8.6	9.8	11.0	13.4	14.7	15.9	17.1	18.3	19.5	20.7
43	1.25	2.50	3.75	5.0	6.2	7.5	8.8	10.0	11.2	13.8	15.0	16.2	17.5	18.8	20.0	21.2
44	1.28	2.56	3.84	5.1	6.4	7.7	9.0	10.2	11.5	14.1	15.4	16.6	17.9	19.2	20.5	21.8
45	1.31	2.62	3.93	5.2	6.5	7.8	9.2	10.5	11.8	14.4	15.7	17.0	18.3	19.6	20.9	22.2
46	1.34	2.63	4.01	5.4	6.7	8.0	9.4	10.7	12.0	14.7	16.1	17.4	18.7	20.1	21.4	22.7
47	1.37	2.73	4.10	5.5	6.8	8.2	9.6	10.9	12.3	15.0	16.4	17.8	19.1	20.5	21.9	23.2
48	1.40	2.79	4.19	5.6	7.0	8.4	9.8	11.2	12.6	15.4	16.8	18.1	19.5	20.9	22.3	23.7
49	1.42	2.85	4.28	5.7	7.1	8.6	10.0	11.4	12.8	15.7	17.1	18.5	20.0	21.4	22.8	24.2
50	1.45	2.91	4.36	5.8	7.3	8.7	10.2	11.6	13.1	16.0	17.4	18.9	20.4	21.8	23.3	24.7
51	1.48	2.97	4.45	5.9	7.4	8.9	10.4	11.9	13.4	16.3	17.8	19.3	20.8	22.2	23.7	25.2
52	1.51	3.02	4.54	6.0	7.6	9.1	10.6	12.1	13.6	16.6	18.2	19.7	21.2	22.7	24.2	25.7
53	1.54	3.08	4.62	6.2	7.7	9.2	10.8	12.3	13.9	17.0	18.5	20.0	21.6	23.1	24.7	26.2
54	1.57	3.14	4.71	6.3	7.8	9.4	11.0	12.6	14.1	17.3	18.8	20.4	22.0	23.6	25.1	26.7
55	1.60	3 20	4.80	6.4	8.0	9.6	11.2	12.8	14.4	17.6	19.2	20.8	22.4	24.0	25.6	27.2
56	1.63	3.26	4.88	6.5	8.1	9.8	11.4	13.0	14.7	17.9	19.5	21.2	22.8	24.4	26.1	27.7
57	1.66	3.32	4.97	6.6	8.3	9.9	11.6	13.3	14.9	18.2	19.9	21.6	23.2	24.9	26.5	28.2
58	1.69	3.37	5.06	6.7	8.4	10.1	11.8	13.5	15.2	18.6	20.2	21.9	23.6	25.3	27.0	28.7
59	1.72	3.43	5.15	6.9	8.6	10.3	12.0	13.7	15.4	18.9	20.6	22.3	24.0	25.7	27.5	29.2
Horz. Dist.	99.99	199.9	299.9	399.9	499.9	599.9	699.9	799.9	899.9	1099	1199	1299	1399	1499	1599	1699

Table III.—(*Continued*)

0°

1800	1900	2100	2200	2300	2400	2500	2600	2700	2800	2900	3100	3200	3300	3400	3500	′
0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1
1.0	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	2.0	2
1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.4	2.5	2.7	2.8	2.9	3.0	3.1	3
2.1	2.2	2.4	2.6	2.7	2.7	2.9	3.0	3.1	3.3	3.4	3.6	3.7	3.8	4.0	4.1	4
2.6	2.8	3.1	3.2	3.4	3.5	3.6	3.8	3.9	4.1	4.2	4.5	4.7	4.8	4.9	5.1	5
3.1	3.3	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4.9	5.1	5.4	5.6	5.8	5.9	6.1	6
3.7	3.9	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.3	6.5	6.7	6.9	7.1	7
4.2	4.4	4.9	5.1	5.3	5.6	5.8	6.0	6.3	6.5	6.7	7.2	7.4	7.7	7.9	8.1	8
4.7	5.0	5.5	5.8	6.0	6.3	6.6	6.8	7.1	7.3	7.6	8.1	8.4	8.6	8.9	9.2	9
5.2	5.5	6.1	6.4	6.7	7.0	7.3	7.6	7.9	8.1	8.4	9.0	9.3	9.6	9.9	10.2	10
5.8	6.1	6.7	7.0	7.4	7.7	8.0	8.3	8.6	9.0	9.3	9.9	10.2	10.6	10.9	11.2	11
6.3	6.6	7.3	7.7	8.0	8.4	8.7	9.1	9.4	9.8	10.1	10.8	11.2	11.5	11.9	12.2	12
6.8	7.2	7.9	8.3	8.7	9.1	9.4	9.8	10.2	10.6	11.0	11.7	12.1	12.5	12.8	13.2	13
7.3	7.7	8.5	9.0	9.4	9.8	10.2	10.6	11.0	11.4	11.8	12.6	13.0	13.4	13.8	14.2	14
7.9	8.2	9.2	9.6	10.0	10.5	10.9	11.3	11.8	12.2	12.7	13.5	14.0	14.4	14.8	15.3	15
8.4	8.8	9.8	10.2	10.7	11.2	11.6	12.1	12.6	13.0	13.5	14.4	14.0	15.4	15.8	16.3	16
8.9	9.4	10.4	10.9	11.4	11.9	12.4	12.9	13.4	13.8	14.3	15.3	15.8	16.3	16.8	17.3	17
9.4	9.9	11.0	11.5	12.0	12.6	13.1	13.6	14.1	14.7	15.2	16.2	16.7	17.3	17.8	18.3	18
9.9	10.5	11.6	12.2	12.7	13.3	13.8	14.4	14.9	15.5	16.0	17.1	17.7	18.2	18.8	19.3	19
10.5	11.1	12.2	12.8	13.4	14.0	14.6	15.1	15.7	16.3	16.9	18.0	18.6	19.2	19.8	20.4	20
11.0	11.6	12.8	13.4	14.0	14.7	15.3	15.9	16.5	17.1	17.7	18.9	19.6	20.2	20.8	21.4	21
11.5	12.2	13.4	14.1	14.7	15.4	16.0	16.6	17.3	17.9	18.6	19.8	20.5	21.1	21.8	22.4	22
12.0	12.7	14.0	14.7	15.4	16.1	16.7	17.4	18.1	18.7	19.4	20.7	21.4	22.1	22.7	23.4	23
12.6	13.3	14.7	15.4	16.0	16.8	17.4	18.1	18.8	19.5	20.2	21.6	22.3	23.0	23.7	24.4	24
13.1	13.8	15.3	16.0	16.7	17.4	18.2	18.9	19.6	20.4	21.1	22.5	23.3	24.0	24.7	25.4	25
13.6	14.4	15.9	16.6	17.4	18.2	18.9	19.7	20.4	21.2	21.9	23.4	24.2	25.0	25.7	26.5	26
14.1	14.9	16.5	17.3	18.1	18.8	19.6	20.4	21.2	22.0	22.8	24.4	25.1	25.9	26.7	27.5	27
14.7	15.5	17.1	17.9	18.7	19.5	20.4	21.2	22.0	22.8	23.6	25.2	26.1	26.9	27.7	28.5	28
15.2	16.0	17.7	18.6	19.4	20.2	21.1	21.9	22.8	23.6	24.5	26.1	27.0	27.8	28.7	29.5	29
15.7	16.6	18.3	19.2	20.1	20.9	21.8	22.7	23.6	24.4	25.3	27.0	27.9	28.8	29.7	30.5	30
16.2	17.1	18.9	19.8	20.7	21.6	22.5	23.4	24.3	25.2	26.1	27.9	28.8	29.7	30.6	31.5	31
16.8	17.7	19.5	20.5	21.4	22.3	23.3	24.2	25.1	26.1	27.0	28.9	29.8	30.7	31.7	32.6	32
17.3	18.2	20.2	21.1	22.1	23.0	24.0	25.0	25.9	26.9	27.8	29.8	30.7	31.7	32.6	33.6	33
17.8	18.8	20.8	21.8	22.7	23.7	24.7	25.7	26.7	27.7	28.7	30.7	31.6	32.6	33.6	34.6	34
18.3	19.3	21.4	22.4	23.4	24.4	25.4	26.5	27.5	28.5	29.5	31.6	32.6	33.6	34.6	35.6	35
18.8	19.9	22.0	23.0	24.1	25.1	26.2	27.2	28.3	29.3	30.4	32.5	33.5	34.6	35.6	36.6	36
19.4	20.4	22.6	23.7	24.7	25.8	26.9	28.0	29.0	30.1	31.2	33.4	34.4	35.4	35.6	37.7	37
19.9	21.0	23.2	24.3	25.4	26.5	27.6	28.7	29.8	30.9	32.1	34.3	35.4	36.5	37.6	38.7	38
20.4	21.6	23.8	25.0	26.1	27.2	28.4	29.5	30.6	31.8	32.9	35.2	36.3	37.4	38.6	39.7	39
20.9	22.1	24.4	25.6	26.8	27.9	29.1	30.2	31.4	32.6	33.7	36.1	37.2	38.4	39.6	40.7	40
21.5	22.7	25.0	26.2	27.4	28.6	29.8	31.0	32.2	33.4	34.6	37.0	38.2	39.4	40.5	41.7	41
22.0	23.2	25.6	26.9	28.1	29.3	30.5	31.8	33.0	34.2	35.4	37.9	39.1	40.3	41.5	42.7	42
22.5	23.8	26.3	27.5	28.8	30.0	31.3	32.5	33.8	35.0	36.3	38.8	40.0	41.3	42.5	43.8	43
23.0	24.3	26.9	28.2	29.4	30.7	32.0	33.3	34.6	35.8	37.1	39.7	41.0	42.2	43.5	44.8	44
23.6	24.9	27.5	28.8	30.1	31.4	32.7	34.0	35.3	36.6	38.0	40.6	41.9	43.2	44.5	45.8	45
24.1	25.4	28.1	29.4	30.8	32.1	33.4	34.8	36.1	37.5	38.8	41.5	42.8	44.2	45.5	46.8	46
24.6	26.0	28.7	30.1	31.4	32.8	34.2	35.5	36.9	38.3	39.6	42.4	43.7	45.1	46.5	47.8	47
25.1	26.5	29.3	30.7	32.1	33.5	34.9	36.3	37.7	39.1	40.5	43.3	44.7	46.1	47.5	48.9	48
25.6	27.1	29.9	31.4	32.8	34.2	35.6	37.0	38.5	39.9	41.3	44.2	45.6	47.0	48.5	49.9	49
26.2	27.6	30.6	32.0	33.0	34.9	36.4	37.8	39.3	40.7	42.2	45.1	46.5	48.0	49.4	50.9	50
26.7	28.2	31.2	32.6	34.2	35.6	37.1	38.6	40.0	41.5	43.0	46.0	47.5	49.0	50.4	51.9	51
27.2	28.7	31.8	33.3	34.8	36.3	37.8	39.3	40.8	42.4	43.9	46.9	48.4	49.9	51.4	52.9	52
27.7	29.3	32.4	33.9	35.4	37.0	38.5	40.1	41.6	43.2	44.7	47.8	49.3	50.9	52.4	54.0	53
28.3	29.8	33.0	34.5	36.1	37.7	39.2	40.8	42.4	44.0	45.5	48.7	50.2	51.8	53.4	55.0	54
28.8	30.4	33.6	35.2	36.8	38.4	40.0	41.6	43.2	44.8	46.4	49.6	51.2	52.8	54.4	56.0	55
29.3	30.9	34.2	35.8	37.5	39.1	40.7	42.3	43.4	45.6	47.2	50.5	52.1	53.7	55.4	57.0	56
29.8	31.5	34.8	36.5	38.1	39.8	41.4	43.1	44.8	46.4	48.1	51.4	53.1	54.7	56.4	58.0	57
30.4	32.0	35.4	37.1	38.8	40.5	42.2	43.9	45.5	47.2	48.9	52.3	54.0	55.7	57.4	59.0	58
30.9	32.6	36.0	37.8	39.5	41.2	42.9	44.6	46.3	48.0	49.8	53.2	54.9	56.6	58.3	60.1	59
1799	1899	2099	2199	2299	2399	2499	2599	2609	2799	2890	3099	3199	3299	3399	3499	Horz. Dist.

1°

′	100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	1700
0	1.74	3.49	5.24	7.0	8.7	10.5	12.2	14.0	15.7	19.2	20.9	22.7	24.4	26.2	27.9	29.7
1	1.77	3.55	5.32	7.1	8.9	10.6	12.4	14.2	16.0	19.5	21.3	23.1	24.8	26.6	28.4	30.2
2	1.80	3.61	5.41	7.2	9.0	10.8	12.6	14.4	16.2	19.8	21.6	23.4	25.2	27.0	28.8	30.6
3	1.83	3.66	5.50	7.3	9.2	11.0	12.8	14.7	16.5	20.1	22.0	23.8	25.6	27.5	29.3	31.1
4	1.86	3.72	5.58	7.4	9.3	11.2	13.0	14.9	16.7	20.5	22.3	24.2	26.1	27.9	29.8	31.6
5	1.89	3.78	5.67	7.6	9.4	11.3	13.2	15.1	17.0	20.8	22.7	24.6	26.5	28.4	30.2	32.1
6	1.92	3.84	5.76	7.7	9.6	11.5	13.4	15.4	17.3	21.1	23.0	24.9	26.8	28.8	30.7	32.6
7	1.95	3.90	5.84	7.8	9.7	11.7	13.6	15.6	17.5	21.4	23.4	25.3	27.3	29.2	31.2	33.1
8	1.98	3.96	5.93	7.9	9.9	11.9	13.8	15.8	17.8	21.7	23.7	25.7	27.7	29.7	31.6	33.6
9	2.01	4.01	6.02	8.0	10.0	12.0	14.0	16.0	18.1	22.1	24.1	26.1	28.1	30.1	32.1	34.1
10	2.04	4.07	6.11	8.1	10.2	12.2	14.2	16.3	18.3	22.4	24.4	26.5	28.5	30.5	32.6	34.6
11	2.06	4.13	6.19	8.3	10.3	12.4	14.4	16.5	18.6	22.7	24.8	26.8	28.9	31.0	33.0	35.1
12	2.09	4.19	6.28	8.4	10.5	12.6	14.7	16.7	18.8	23.0	25.1	27.2	29.3	31.4	33.5	35.6
13	2.12	4.25	6.37	8.5	10.6	12.7	14.9	17.0	19.1	23.3	25.5	27.6	29.7	31.8	34.0	36.1
14	2.15	4.30	6.46	8.6	10.8	12.9	15.1	17.2	19.4	23.7	25.8	28.0	30.1	32.3	34.4	36.6
15	2.18	4.36	6.54	8.7	10.9	13.1	15.3	17.4	19.6	24.0	26.2	28.4	30.5	32.7	34.9	37.1
16	2.21	4.42	6.63	8.8	11.0	13.3	15.5	17.7	19.9	24.3	26.5	28.7	30.9	33.2	35.4	37.6
17	2.24	4.48	6.72	9.0	11.2	13.4	15.7	17.9	20.2	24.6	26.9	29.1	31.3	33.6	35.8	38.1
18	2.27	4.54	6.80	9.1	11.3	13.6	15.9	18.1	20.4	24.9	27.2	29.5	31.7	34.0	36.3	38.6
19	2.30	4.59	6.89	9.2	11.5	13.8	16.1	18.4	20.7	25.3	27.6	29.9	32.2	34.5	36.8	39.0
20	2.33	4.65	6.98	9.3	11.6	14.0	16.3	18.6	20.9	25.6	27.9	30.2	62.6	34.9	37.2	39.6
21	2.36	4.71	7.07	9.4	11.8	14.1	16.5	18.8	21.2	25.9	28.3	30.6	33.0	35.3	37.7	40.0
22	2.38	4.77	7.15	9.5	11.9	14.3	16.7	19.1	21.5	26.2	28.6	31.0	33.4	35.8	38.1	40.5
23	2.41	4.83	7.24	9.6	12.1	14.5	16.9	19.3	21.7	26.5	29.0	31.4	33.8	36.2	38.6	41.0
24	2.44	4.88	7.33	9.8	12.2	14.7	17.1	19.5	22.0	26.9	29.3	31.8	34.2	36.6	39.1	41.5
25	2.47	4.94	7.41	9.9	12.4	14.8	17.3	19.8	22.2	27.2	29.7	32.1	34.6	37.1	39.5	42.0
26	2.50	5.00	7.50	10.0	12.5	15.0	17.5	20.0	22.5	27.5	30.0	32.5	35.0	37.5	40.0	42.5
27	2.53	5.06	7.59	10.1	12.6	15.2	17.7	20.2	22.8	27.8	30.3	32.9	35.4	37.9	40.5	43.0
28	2.56	5.12	7.68	10.2	12.8	15.4	17.9	20.5	23.0	28.1	30.7	33.3	35.8	38.4	40.9	43.5
29	2.59	5.18	7.76	10.4	12.9	15.5	18.1	20.7	23.3	28.5	31.0	33.6	36.2	38.8	41.4	44.0
30	2.62	5.23	7.85	10.5	13.1	15.7	18.3	20.9	23.6	28.8	31.4	34.0	36.6	39.3	41.9	44.5
31	2.65	5.29	7.94	10.6	13.2	15.9	18.5	21.2	23.8	29.1	31.8	34.4	37.0	39.7	42.3	45.0
32	2.68	5.35	8.02	10.7	13.4	16.0	18.7	21.4	24.1	29.4	32.1	34.8	37.4	40.1	42.8	45.5
33	2.70	5.41	8.11	10.8	13.5	16.2	18.9	21.6	24.3	29.7	32.4	35.2	37.9	40.6	43.3	46.0
34	2.73	5.47	8.20	10.9	13.7	16.4	19.1	21.9	24.6	30.1	32.8	35.5	38.3	41.0	43.7	46.5
35	2.76	5.52	8.29	11.0	13.8	16.6	19.3	22.1	24.9	30.4	33.1	35.9	38.7	41.4	44.2	47.0
36	2.79	5.58	8.37	11.2	14.0	16.7	19.5	22.3	25.1	30.7	33.5	36.3	39.1	41.9	44.7	47.4
37	2.82	5.64	8.46	11.3	14.1	16.9	19.7	22.6	25.4	31.0	33.8	36.7	39.5	42.3	45.1	47.9
38	2.85	5.70	8.55	11.4	14.2	17.1	19.9	22.8	25.6	31.3	34.2	37.0	39.9	42.7	45.6	48.4
39	2.88	5.76	8.63	11.5	14.4	17.3	20.1	23.0	25.9	31.7	34.5	37.4	40.3	43.2	46.0	48.9
40	2.91	5.81	8.72	11.6	14.5	17.4	20.3	23.3	26.2	32.0	34.9	37.8	40.7	43.6	46.5	49.4
41	2.94	5.87	8.81	11.8	14.7	17.6	20.6	23.5	26.4	32.3	35.2	38.2	41.1	44.0	47.0	49.9
42	2.97	5.93	8.90	11.9	14.8	17.8	20.8	23.7	26.7	32.6	35.6	38.6	41.5	44.5	47.4	50.4
43	3.00	5.99	8.98	12.0	15.0	18.0	21.0	24.0	27.0	32.9	35.9	38.9	41.9	44.9	47.9	50.9
44	3.02	6.05	9.07	12.1	15.1	18.1	21.2	24.2	27.2	33.3	36.3	39.3	42.3	45.3	48.4	51.4
45	3.05	6.10	9.16	12.2	15.3	18.3	21.4	24.4	27.5	33.6	36.6	39.7	42.7	45.8	48.8	51.9
46	3.08	6.16	9.24	12.3	15.4	18.5	21.6	24.6	27.7	33.9	37.0	40.1	43.1	46.2	49.3	52.4
47	3.11	6.22	9.33	12.4	15.6	18.7	21.8	24.9	28.0	34.2	37.3	40.4	43.5	46.7	49.8	52.9
48	3.14	6.28	9.42	12.6	15.7	18.8	22.0	25.1	28.3	34.5	37.7	40.8	43.9	47.1	50.2	53.4
49	3.17	6.34	9.50	12.7	15.8	19.0	22.2	25.3	28.5	34.8	38.0	41.2	44.4	47.5	50.7	53.9
50	3.20	6.40	9.59	12.8	16.0	19.2	22.4	25.6	28.8	35.2	38.4	41.6	44.8	48.0	51.2	54.4
51	3.23	6.45	9.68	12.9	16.1	19.4	22.6	25.8	29.0	35.5	38.7	41.9	45.2	48.4	51.6	54.8
52	3.26	6.51	9.77	13.0	16.3	19.5	22.8	26.0	29.3	35.8	39.1	42.3	45.6	48.8	52.1	55.3
53	3.29	6.57	9.85	13.1	16.4	19.7	23.0	26.3	29.6	36.1	39.4	42.7	46.0	49.3	52.6	55.8
54	3.31	6.63	9.94	13.2	16.6	19.9	23.2	26.5	29.8	36.4	39.8	43.1	46.4	49.7	53.0	56.3
55	3.34	6.68	10.03	13.4	16.7	20.1	23.4	26.7	30.1	36.8	40.1	43.4	46.8	50.1	53.5	56.8
56	3.37	6.74	10.11	13.5	16.9	20.2	23.6	27.0	30.3	37.1	40.5	43.8	47.2	50.6	53.9	57.3
57	3.40	6.80	10.20	13.6	17.0	20.4	23.8	27.2	30.6	37.4	40.8	44.2	47.6	51.0	54.4	57.8
58	3.43	6.86	10.29	13.7	17.2	20.6	24.0	27.4	30.9	37.7	41.2	44.6	48.0	51.5	54.9	58.3
59	3.46	6.92	10.38	13.8	17.3	20.7	24.2	27.7	31.1	38.0	41.5	45.0	48.4	51.9	55.3	58.8
Horz. Dist.	99.93	199.9	299.8	399.7	499.6	599	699	799	899	1099	1199	1299	1399	1499	1599	1699

1°

1800	1900	2100	2200	2300	2400	2500	2600	2700	2800	2900	3100	3200	3300	3400	3500	′
31.4	33.2	36.6	38.4	40.1	41.9	43.6	45.4	47.1	48.9	50.6	54.0	55.8	57.6	59.3	61.1	0
31.9	33.7	37.2	39.0	40.8	42.6	44.4	46.1	47.9	49.7	51.4	55.0	56.8	58.5	60.3	62.1	1
32.4	34.3	37.9	39.7	41.5	43.3	45.1	46.9	48.7	50.5	52.3	55.9	57.7	59.5	61.3	63.1	2
33.0	34.8	38.5	40.3	42.1	44.0	45.8	47.6	49.5	51.3	53.1	56.8	58.6	60.5	62.3	64.1	3
33.5	35.4	39.1	40.9	42.8	44.7	46.5	48.4	50.3	52.1	54.0	57.7	59.6	61.4	63.3	65.1	4
34.0	35.9	39.7	41.6	43.5	45.4	47.3	49.1	51.0	52.9	54.8	58.6	60.5	62.4	64.3	66.2	5
34.5	36.5	40.3	42.2	44.1	46.1	48.0	49.9	51.8	53.7	55.7	59.5	61.4	63.3	65.3	67.2	6
35.1	37.0	40.9	42.9	44.8	46.7	48.7	50.6	52.6	54.5	56.5	60.4	62.3	64.3	66.2	68.2	7
35.6	37.6	41.5	43.5	45.5	47.5	49.4	51.4	53.4	55.4	57.3	61.3	63.3	65.3	67.2	69.2	8
36.1	38.1	42.1	44.1	46.1	48.2	50.2	52.2	54.2	56.2	58.2	62.2	64.2	66.2	68.2	70.2	9
36.6	38.7	42.7	44.8	46.8	48.8	50.9	52.9	55.0	57.0	59.0	63.1	65.1	67.2	69.2	71.2	10
37.2	39.2	43.3	45.4	47.5	49.5	51.6	53.7	55.7	57.8	59.9	64.0	66.1	68.1	70.2	72.3	11
37.7	39.8	44.0	46.1	48.2	50.3	52.4	54.4	56.5	58.6	60.7	64.9	67.0	69.1	71.2	73.3	12
38.2	40.3	44.6	46.7	48.8	50.9	53.1	55.2	57.3	59.4	61.6	65.8	67.9	70.1	72.2	74.3	13
38.7	40.9	45.2	47.3	49.5	51.6	53.8	55.9	58.1	60.3	62.4	66.7	68.9	71.0	73.2	75.3	14
39.3	41.4	45.8	48.0	50.2	52.3	54.5	56.7	58.9	61.1	63.2	67.6	69.8	72.0	74.1	76.3	15
39.8	42.0	46.4	48.6	50.8	53.0	55.2	57.5	59.7	61.9	64.1	68.5	70.7	72.9	75.1	77.4	16
40.3	42.5	47.0	49.3	51.5	53.7	56.0	58.2	60.5	62.7	64.9	69.4	71.6	73.9	76.1	78.4	17
40.8	43.1	47.6	49.9	52.2	54.4	56.7	59.0	61.2	63.5	65.8	70.3	72.6	74.8	77.1	79.4	18
41.3	43.6	48.2	50.5	52.8	55.1	57.4	59.7	62.0	64.3	66.6	71.2	73.5	75.8	78.1	80.4	19
41.9	44.2	48.9	51.2	53.5	55.8	58.2	60.5	62.8	65.1	67.5	72.1	74.4	76.8	79.1	81.4	20
42.4	44.8	49.5	51.8	54.2	56.5	58.9	61.2	63.6	65.9	68.3	73.0	75.4	77.7	80.1	82.4	21
42.9	45.3	50.1	52.5	54.8	57.2	59.6	62.0	64.4	66.8	69.2	73.9	76.3	78.7	81.1	83.5	22
43.4	45.9	50.7	53.1	55.5	57.9	60.3	62.8	65.2	67.6	70.0	74.8	77.2	79.6	82.1	84.5	23
44.0	46.4	51.3	53.7	56.2	58.6	61.1	63.5	65.9	68.4	70.8	75.7	78.2	80.6	83.0	85.5	24
44.5	47.0	51.9	54.4	56.8	59.3	61.8	64.3	66.7	69.2	71.7	76.6	79.1	81.6	84.0	86.5	25
45.0	47.5	52.5	55.0	57.5	60.0	62.5	65.0	67.5	70.0	72.5	77.5	80.0	82.5	85.0	87.5	26
45.5	48.1	53.1	55.6	58.2	60.7	63.2	65.8	68.3	70.8	73.4	78.4	80.9	83.5	86.0	88.5	27
46.0	48.6	53.7	56.3	58.8	61.4	64.0	66.5	69.1	71.6	74.2	79.3	81.9	84.5	87.0	89.5	28
46.6	49.2	54.3	56.9	59.5	62.1	64.7	67.3	69.9	72.5	75.0	80.2	82.8	85.4	88.0	90.6	29
47.1	49.7	55.0	57.6	60.2	62.8	65.4	68.0	70.7	73.3	75.9	81.1	83.7	86.4	89.0	91.6	30
47.6	50.3	55.6	58.2	60.9	63.5	66.2	68.8	71.4	74.1	76.7	82.0	84.7	87.3	90.0	92.6	31
48.2	50.8	56.2	58.8	61.5	64.2	66.9	69.6	72.2	74.9	77.6	82.9	85.6	88.3	91.0	93.6	32
48.7	51.4	56.8	59.5	62.2	64.9	67.6	70.3	73.0	75.7	78.4	83.8	86.5	89.2	91.9	94.6	33
49.2	51.9	57.4	60.1	62.9	65.6	68.3	71.1	73.8	76.5	79.3	84.7	87.5	90.2	92.9	95.7	34
49.7	52.5	58.0	60.8	63.5	66.3	69.0	71.8	74.6	77.3	80.1	85.6	88.4	91.1	93.9	96.7	35
50.2	53.0	58.6	61.4	64.2	67.0	69.8	72.6	75.4	78.1	80.9	86.5	89.3	92.1	94.9	97.7	36
50.8	53.6	59.2	62.0	64.9	67.7	70.5	73.3	76.1	79.0	81.8	87.4	90.2	93.1	95.9	98.7	37
51.3	54.1	59.8	62.7	65.5	68.4	71.2	74.1	76.9	79.8	82.6	88.3	91.2	94.0	96.9	99.7	38
51.8	54.7	60.4	63.3	66.2	69.1	72.0	74.8	77.7	80.6	83.5	89.1	92.1	95.0	97.8	100.7	39
52.3	55.2	61.0	64.0	66.9	69.8	72.7	75.6	78.5	81.4	84.3	90.1	93.0	95.9	98.8	101.7	40
52.9	55.8	61.7	64.6	67.5	70.5	73.4	76.3	79.3	82.2	85.2	91.0	94.0	96.9	99.8	102.8	41
53.4	56.3	62.3	65.2	68.2	71.2	74.1	77.1	80.1	83.0	86.0	91.9	94.9	97.9	100.8	103.8	42
53.9	56.9	62.9	65.9	68.9	71.9	74.9	77.9	80.9	83.9	86.9	92.8	95.8	98.8	101.8	104.8	43
54.4	57.4	63.5	66.5	69.5	72.6	75.6	78.6	81.6	84.7	87.7	93.7	96.7	99.8	102.8	105.8	44
54.9	58.0	64.1	67.2	70.2	73.3	76.3	79.4	82.4	85.5	88.5	94.6	97.7	100.7	103.8	106.8	45
55.5	58.5	64.7	67.8	70.9	74.0	77.0	80.1	83.2	86.3	89.4	95.5	98.6	101.7	104.8	107.8	46
56.0	59.1	65.3	68.4	71.5	74.6	77.8	80.9	84.0	87.1	90.2	96.4	99.5	102.6	105.8	108.9	47
56.5	59.7	65.9	69.1	72.2	75.3	78.5	81.6	84.8	87.9	91.0	97.3	100.5	103.6	106.7	109.9	48
57.0	60.2	66.5	69.7	72.9	76.0	79.2	82.4	85.5	88.7	91.9	98.2	101.4	104.6	107.7	110.9	49
57.6	60.8	67.1	70.3	73.5	76.7	80.0	83.1	86.3	89.5	92.7	99.1	102.3	105.5	108.7	111.9	50
58.1	61.3	67.8	71.0	74.2	77.4	80.7	83.9	87.1	90.3	93.6	100.0	103.2	106.5	109.7	112.9	51
58.6	61.8	68.4	71.6	74.9	78.1	81.4	84.6	87.9	91.2	94.4	100.9	104.2	107.4	110.7	113.9	52
59.1	62.4	69.0	72.3	75.5	78.8	82.1	85.4	88.7	92.0	95.2	101.8	105.1	108.4	111.7	115.0	53
59.6	63.0	69.6	72.9	76.2	79.5	82.8	86.2	89.5	92.8	96.1	102.7	106.0	109.3	112.7	116.0	54
60.2	63.5	70.2	73.5	76.9	80.2	83.6	86.9	90.2	93.6	96.9	103.6	107.0	110.3	113.6	117.0	55
60.7	64.1	70.8	74.2	77.6	80.9	84.3	87.7	91.0	94.4	97.8	104.5	107.9	111.3	114.6	118.0	56
61.2	64.6	71.4	74.8	78.2	81.6	85.0	88.4	91.8	95.2	98.6	105.4	108.8	112.2	115.6	119.0	57
61.7	65.2	72.0	75.5	78.9	82.3	85.8	89.1	92.6	96.0	99.5	106.3	109.8	113.2	116.6	120.0	58
62.3	65.7	72.6	76.1	79.6	83.0	86.5	89.9	93.4	96.8	100.3	107.2	110.7	114.1	117.6	121.1	59
1799	1899	2098	2198	2298	2398	2498	2598	2698	2798	2898	3098	3198	3298	3398	3498	Horz. Dist.

Table III.—(*Continued*)

2°

′	100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	1700
0	3.49	6.98	10.46	14.0	17.4	20.9	24.4	27.9	31.4	38.4	41.9	45.3	48.8	52.3	55.8	59.3
1	3.52	7.03	10.55	14.1	17.6	21.1	24.6	28.1	31.7	38.7	42.2	45.7	49.2	52.8	56.3	59.8
2	3.55	7.09	10.64	14.2	17.7	21.3	24.8	28.4	31.9	39.0	42.6	46.1	49.6	53.2	56.7	60.3
3	3.58	7.15	10.72	14.3	17.9	21.4	25.0	28.6	32.2	39.3	42.9	46.5	50.0	53.6	57.2	60.8
4	3.60	7.21	10.81	14.4	18.0	21.6	25.2	28.8	32.4	39.6	43.2	46.8	50.5	54.1	57.7	61.3
5	3.63	7.27	10.90	14.5	18.2	21.8	25.4	29.1	32.7	40.0	43.6	47.2	50.9	54.5	58.1	61.8
6	3.66	7.32	10.99	14.6	18.3	22.0	25.6	29.3	33.0	40.3	43.9	47.6	51.3	54.9	58.6	62.2
7	3.69	7.38	11.07	14.8	18.5	22.1	25.8	29.5	33.2	40.6	44.3	48.0	51.7	55.4	59.1	62.7
8	3.72	7.44	11.16	14.9	18.6	22.3	26.0	29.8	33.5	40.9	44.6	48.4	52.1	55.8	59.5	63.2
9	3.75	7.50	11.25	15.0	18.7	22.5	26.2	30.0	33.7	41.2	45.0	48.7	52.5	56.2	60.0	63.7
10	3.78	7.56	11.33	15.1	18.9	22.7	26.4	30.2	34.0	41.6	45.3	49.1	52.9	56.7	60.4	64.2
11	3.81	7.61	11.42	15.2	19.0	22.8	26.6	30.5	34.3	41.9	45.7	49.5	53.3	57.1	60.9	64.7
12	3.84	7.67	11.51	15.3	19.2	23.0	26.8	30.7	34.5	42.2	46.0	49.9	53.7	57.5	61.4	65.2
13	3.86	7.73	11.60	15.5	19.3	23.2	27.1	30.9	34.8	42.5	46.4	50.2	54.1	58.0	61.8	65.7
14	3.89	7.79	11.68	15.6	19.5	23.4	27.3	31.1	35.0	42.8	46.7	50.6	54.5	58.4	62.3	66.2
15	3.92	7.85	11.77	15.7	19.6	23.5	27.5	31.4	35.3	43.1	47.1	51.0	54.9	58.8	62.8	66.7
16	3.95	7.90	11.86	15.8	19.8	23.7	27.7	31.6	35.6	43.5	47.4	51.4	55.3	59.3	63.2	67.2
17	3.98	7.96	11.94	15.9	19.9	23.9	27.9	31.8	35.8	43.8	47.8	51.7	55.7	59.7	63.7	67.7
18	4.01	8.02	12.03	16.0	20.0	24.1	28.1	32.1	36.1	44.1	48.1	52.1	56.1	60.2	64.2	68.2
19	4.04	8.08	12.12	16.2	20.2	24.2	28.3	32.3	36.3	44.4	48.5	52.5	56.5	60.6	64.6	68.7
20	4.07	8.14	12.20	16.3	20.3	24.4	28.5	32.5	36.6	44.7	48.8	52.9	56.9	61.0	65.1	69.2
21	4.10	8.19	12.29	16.4	20.5	24.6	28.7	32.8	36.9	45.1	49.2	53.3	57.4	61.5	65.6	69.6
22	4.13	8.25	12.38	16.5	20.6	24.8	28.9	33.0	37.1	45.4	49.5	53.6	57.8	61.9	66.0	70.1
23	4.16	8.31	12.46	16.6	20.8	24.9	29.1	33.2	37.4	45.7	49.9	54.0	58.2	62.3	66.5	70.6
24	4.18	8.37	12.55	16.7	20.9	25.1	29.3	33.5	37.7	46.0	50.2	54.4	58.6	62.8	66.9	71.1
25	4.21	8.43	12.64	16.8	21.1	25.3	29.5	33.7	37.9	46.3	50.6	54.8	59.0	63.2	67.4	71.6
26	4.24	8.48	12.73	17.0	21.2	25.4	29.7	33.9	38.2	46.7	50.9	55.1	59.4	63.6	67.9	72.1
27	4.27	8.54	12.81	17.1	21.4	25.6	29.9	34.2	38.4	47.0	51.2	55.5	59.8	64.1	68.3	72.6
28	4.30	8.60	12.90	17.2	21.5	25.8	30.1	34.4	38.7	47.3	51.6	55.9	60.2	64.5	68.8	73.1
29	4.33	8.66	12.99	17.3	21.6	26.0	30.3	34.6	39.0	47.6	51.9	56.3	60.6	64.9	69.3	73.6
30	4.36	8.716	13.07	17.4	21.8	26.1	30.5	34.9	39.2	47.9	52.3	56.6	61.0	65.4	69.7	74.1
31	4.39	8.774	13.16	17.5	21.9	26.3	30.7	35.1	39.5	48.3	52.6	57.0	61.4	65.8	70.2	74.6
32	4.42	8.831	13.25	17.7	22.1	26.5	30.9	35.3	39.7	48.6	53.0	57.4	61.8	66.2	70.6	75.1
33	4.44	8.889	13.33	17.8	22.2	26.7	31.1	35.6	40.0	48.9	53.3	57.8	62.2	66.7	71.1	75.6
34	4.47	8.947	13.42	17.9	22.4	26.8	31.3	35.8	40.3	49.2	53.7	58.2	62.6	67.1	71.6	76.0
35	4.50	9.005	13.51	18.0	22.5	27.0	31.5	36.0	40.5	49.5	54.0	58.5	63.0	67.5	72.0	76.5
36	4.53	9.063	13.59	18.1	22.7	27.2	31.7	36.2	40.8	49.8	54.4	58.9	63.4	68.0	72.5	77.1
37	4.56	9.121	13.68	18.2	22.8	27.4	31.9	36.5	41.0	50.2	54.7	59.3	63.8	68.4	73.0	77.5
38	4.59	9.179	13.77	18.4	22.9	27.5	32.1	36.7	41.3	50.5	55.1	59.7	64.2	68.8	73.4	78.0
39	4.62	9.237	13.86	18.5	23.1	27.7	32.3	36.9	41.6	50.8	55.4	60.0	64.7	69.3	73.9	78.5
40	4.65	9.295	13.94	18.6	23.2	27.9	32.5	37.2	41.8	51.1	55.8	60.4	65.1	69.7	74.4	79.0
41	4.68	9.353	14.03	18.7	23.4	28.1	32.7	37.4	42.1	51.4	56.1	60.8	65.5	70.1	74.8	79.5
42	4.71	9.411	14.12	18.8	23.5	28.2	32.9	37.6	42.3	51.8	56.5	61.2	65.9	70.6	75.3	80.0
43	4.73	9.469	14.20	18.9	23.7	28.4	33.1	37.9	42.6	52.1	56.8	61.5	66.3	71.0	75.8	80.5
44	4.76	9.527	14.29	19.0	23.8	28.6	33.3	38.1	42.9	52.4	57.2	61.9	66.7	71.4	76.3	81.0
45	4.79	9.585	14.38	19.2	24.0	28.8	33.5	38.3	43.1	52.7	57.5	62.3	67.1	71.9	76.7	81.5
46	4.82	9.642	14.46	19.3	24.1	28.9	33.7	38.6	43.4	53.0	57.8	62.7	67.5	72.3	77.1	82.0
47	4.85	9.700	14.55	19.4	24.2	29.1	34.0	38.8	43.6	53.4	58.2	63.0	67.9	72.8	77.6	82.4
48	4.88	9.758	14.64	19.5	24.4	29.3	34.1	39.0	43.9	53.7	58.5	63.4	68.3	73.2	78.1	82.9
49	4.91	9.816	14.72	19.6	24.5	29.4	34.4	39.3	44.2	54.0	58.9	63.8	68.7	73.6	78.5	83.4
50	4.94	9.874	14.81	19.7	24.7	29.6	34.6	39.5	44.4	54.3	59.2	64.2	69.1	74.1	79.0	83.9
51	4.97	9.932	14.90	19.9	24.8	29.8	34.8	39.7	44.7	54.6	59.6	64.6	69.5	74.5	79.5	84.4
52	5.00	9.990	14.98	20.0	25.0	30.0	35.0	40.0	45.0	54.9	59.9	64.9	69.9	74.9	79.9	84.9
53	5.02	10.048	15.07	20.1	25.1	30.1	35.2	40.2	45.2	55.3	60.3	65.3	70.3	75.4	80.4	85.4
54	5.05	10.106	15.16	20.2	25.3	30.3	35.4	40.4	45.5	55.6	60.6	65.7	70.7	75.8	80.8	85.9
55	5.08	10.164	15.25	20.3	25.4	30.5	35.6	40.7	45.7	55.9	61.0	66.1	71.1	76.2	81.3	86.4
56	5.11	10.222	15.33	20.4	25.6	30.7	35.8	40.9	46.0	56.2	61.3	66.4	71.5	76.7	81.8	86.9
57	5.14	10.280	15.42	20.6	25.7	30.8	36.0	41.1	46.3	56.5	61.7	66.8	71.9	77.1	82.2	87.4
58	5.17	10.338	15.51	20.7	25.8	31.0	36.2	41.3	46.5	56.8	62.0	67.2	72.4	77.5	82.7	87.9
59	5.20	10.396	15.59	20.8	26.0	31.2	36.4	41.6	46.8	57.2	62.4	67.6	72.8	78.0	83.2	88.4
Horz. Dist.	99.81	199.6	299.4	399.2	499.0	599	699	798	898	1098	1198	1297	1397	1497	1597	1697

TABLE III.—(*Continued*)

2°

1800	1900	2100	2200	2300	2400	2500	2600	2700	2800	2900	3100	3200	3300	3400	3500	′
62.8	66.3	73.2	76.7	80.2	83.7	87.2	90.7	94.2	97.7	101.1	108.1	111.6	115.1	118.6	122.1	0
63.3	66.8	73.9	77.4	80.9	84.4	87.9	91.4	95.0	98.5	102.0	109.0	112.5	116.1	119.6	123.1	1
63.8	67.4	74.5	78.0	81.6	85.1	88.6	92.2	95.7	99.3	102.8	109.9	113.5	117.0	120.6	124.1	2
64.4	67.9	75.1	78.6	82.2	85.8	89.4	93.0	96.5	100.1	103.7	110.8	114.4	118.0	121.6	125.1	3
64.9	68.8	75.7	79.3	82.9	86.5	90.1	93.7	97.3	100.9	104.5	111.9	115.4	118.9	122.5	126.2	4
65.4	69.0	76.3	79.9	83.6	87.2	90.8	94.5	98.1	101.7	105.4	112.6	116.3	119.9	123.5	127.2	5
65.9	69.6	76.9	80.6	84.2	87.9	91.6	95.2	98.9	102.5	106.2	113.5	117.2	120.8	124.5	128.2	6
66.4	70.1	77.5	81.2	84.9	88.6	92.3	96.0	99.7	103.3	107.0	114.4	118.1	121.8	125.5	129.2	7
67.0	70.7	78.1	81.8	85.6	89.3	93.0	96.7	100.4	104.2	107.9	115.3	119.0	122.8	126.5	130.2	8
67.5	71.2	78.7	82.5	86.2	90.0	93.7	97.5	101.2	105.0	108.7	116.2	120.0	123.7	127.5	131.2	9
68.0	71.8	79.3	83.1	86.9	90.7	94.5	98.2	102.0	105.8	109.6	117.1	120.9	124.7	128.4	132.2	10
68.5	72.3	79.9	83.7	87.6	91.4	95.2	99.0	102.8	106.6	110.4	118.0	121.8	125.6	129.4	133.2	11
69.0	72.9	80.6	84.4	88.2	92.0	95.9	99.7	103.6	107.4	111.2	118.9	122.7	126.6	130.4	134.3	12
69.6	73.4	81.2	85.0	88.9	92.8	96.6	100.5	104.4	108.2	112.1	119.8	123.7	127.5	131.4	135.3	13
70.1	74.0	81.8	85.7	89.6	93.5	97.4	101.2	105.1	109.0	112.9	120.7	124.6	128.5	132.4	136.3	14
70.6	74.5	82.4	86.3	90.2	94.1	98.1	102.0	105.9	109.8	113.8	121.6	125.5	129.5	133.4	137.3	15
71.1	75.1	83.0	86.9	90.9	94.8	98.8	102.7	106.7	110.7	114.6	122.5	126.5	130.4	134.4	138.3	16
71.7	75.6	83.6	87.6	91.6	95.5	99.5	103.5	107.5	111.5	115.4	123.4	127.4	131.4	135.3	139.3	17
72.7	76.2	84.2	88.2	92.2	96.2	100.2	104.3	108.3	112.3	116.3	124.3	128.3	132.3	136.3	140.4	18
72.7	76.7	84.8	88.9	92.9	96.9	101.0	105.0	109.0	113.1	117.1	125.2	129.2	133.3	137.3	141.4	19
73.2	77.3	85.4	89.5	93.6	97.6	101.7	105.8	109.8	113.9	118.0	126.1	130.2	134.2	138.3	142.4	20
73.7	77.8	86.0	90.1	94.2	98.3	102.4	106.5	110.6	114.7	118.8	127.0	131.1	135.2	139.3	143.4	21
74.3	78.4	86.6	90.8	94.9	99.0	103.2	107.3	111.4	115.5	119.6	127.9	132.0	136.2	140.3	144.4	22
74.8	78.9	87.3	91.4	95.6	99.7	103.9	108.0	112.2	116.3	120.5	128.8	133.0	137.1	141.3	145.4	23
75.3	79.5	87.9	92.0	96.2	100.4	104.6	108.8	113.0	117.1	121.3	129.7	133.9	138.1	142.3	146.4	24
75.8	80.0	88.5	92.7	96.9	101.1	105.3	109.5	113.7	118.0	122.2	130.6	134.8	139.0	143.2	147.5	25
76.4	80.6	89.1	93.3	97.6	101.8	106.0	110.3	114.5	118.8	123.0	131.5	135.7	140.0	144.2	148.5	26
76.9	81.1	89.7	94.0	98.2	102.5	106.8	111.0	115.3	119.6	123.9	132.4	136.7	141.9	145.2	149.5	27
77.4	81.7	90.3	94.6	98.9	103.2	107.5	111.8	116.1	120.4	124.7	133.3	137.6	141.9	146.2	150.5	28
77.9	82.2	90.9	95.3	99.6	103.9	108.2	112.5	116.9	121.2	125.5	134.2	138.5	142.9	147.2	151.5	29
78.4	82.8	91.5	95.9	100.2	104.6	109.0	113.3	117.7	122.0	126.4	135.1	139.5	143.8	148.2	152.5	30
79.0	83.3	92.1	96.5	100.9	105.3	109.7	114.1	118.4	122.8	127.2	136.0	140.4	144.8	149.2	153.5	31
79.5	83.9	92.7	97.1	101.6	106.0	110.4	114.8	119.2	123.6	128.0	136.9	141.3	145.7	150.1	154.5	32
80.0	84.4	93.3	97.8	102.2	106.7	111.1	115.6	120.0	124.4	128.9	137.8	142.2	146.7	151.1	155.6	33
80.5	85.0	93.9	98.4	102.9	107.4	111.8	116.3	120.8	125.3	129.7	138.7	143.1	147.6	152.1	156.6	34
81.0	85.5	94.6	99.1	103.6	108.1	112.6	117.1	121.6	126.1	130.6	139.6	144.1	148.6	153.1	157.6	35
81.6	86.1	95.2	99.7	104.2	108.8	113.3	117.8	122.3	126.9	131.4	140.5	145.0	149.5	154.1	158.6	36
82.1	86.7	95.8	100.3	104.9	109.5	114.0	118.6	123.1	127.7	132.2	141.4	145.9	150.5	155.1	159.6	37
82.6	87.2	96.4	101.0	105.6	110.1	114.7	119.3	123.9	128.5	133.1	142.3	146.9	151.4	156.0	160.6	38
83.1	87.8	97.0	101.6	106.2	110.9	115.5	120.1	124.7	129.3	133.9	143.2	147.8	152.4	157.0	161.6	39
83.7	88.3	97.6	102.2	106.9	111.5	116.2	120.8	125.5	130.1	134.8	144.1	148.7	153.4	158.0	162.7	40
84.2	88.9	98.2	102.9	107.6	112.2	116.9	121.6	126.3	130.9	135.6	145.0	149.6	154.3	159.0	163.7	41
84.7	89.4	98.8	103.5	108.2	112.9	117.6	122.3	127.0	131.7	136.5	145.9	150.6	155.3	160.0	164.7	42
85.2	90.0	99.4	104.2	108.9	113.6	118.4	123.1	127.8	132.6	137.3	146.8	151.5	156.2	161.0	165.7	43
85.7	90.5	100.0	104.8	109.6	114.3	119.1	123.8	128.6	133.4	138.1	147.7	152.4	157.2	162.0	166.7	44
86.3	91.1	100.6	105.4	110.2	115.0	119.8	124.6	129.4	134.2	139.0	148.6	153.4	158.1	162.9	167.7	45
86.8	91.6	101.2	106.1	110.9	115.7	120.5	125.3	130.2	135.0	139.8	149.4	154.3	159.1	163.9	168.7	46
87.3	92.2	101.8	106.7	111.6	116.4	121.2	126.1	131.0	135.8	140.6	150.4	155.2	160.0	164.9	169.8	47
87.8	92.7	102.5	107.3	112.2	117.1	122.0	126.8	131.7	136.6	141.5	151.2	156.1	161.0	165.9	170.8	48
88.3	93.2	103.1	108.0	112.9	117.8	122.7	127.6	132.5	137.4	142.3	152.1	157.1	162.0	166.9	171.8	49
88.9	93.8	103.7	108.6	113.6	118.5	123.4	128.4	133.3	138.2	143.2	153.0	158.0	162.9	167.9	172.8	50
89.4	94.3	104.3	109.3	114.2	119.2	124.2	129.1	134.1	139.0	144.0	153.9	158.9	163.9	168.8	173.8	51
89.9	94.9	104.9	109.9	114.9	119.9	124.9	129.9	134.9	139.9	144.9	154.8	159.8	164.8	169.8	174.8	52
90.4	95.5	105.5	110.5	115.6	120.6	125.6	130.6	135.6	140.7	145.7	155.7	160.8	165.8	170.8	175.9	53
90.9	96.0	106.1	111.2	116.2	121.3	126.3	131.4	136.4	141.5	146.5	156.6	161.7	166.7	171.8	176.9	54
91.5	96.6	106.7	111.8	116.9	122.0	127.0	132.1	137.2	142.3	147.4	157.5	162.6	167.7	172.8	177.9	55
92.0	97.1	107.3	112.4	117.5	122.6	127.8	132.9	138.0	143.1	143.2	158.4	163.5	168.6	173.8	178.9	56
92.5	97.7	107.9	113.1	118.2	123.3	128.5	133.6	138.8	143.9	149.0	159.3	164.5	169.6	174.7	179.9	57
93.0	98.2	108.5	113.7	118.9	124.0	129.2	134.4	139.5	144.7	149.9	160.2	165.4	170.6	175.7	180.9	58
93.6	98.7	109.1	114.3	119.5	124.7	129.9	135.1	140.3	145.5	150.7	161.1	166.3	171.5	176.7	181.9	59
1797	1896	2096	2196	2296	2395	2495	2595	2695	2795	2894	3094	3194	3294	3393	3493	Horz. Dist.

Table III.—(*Continued*)

3°

′	100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	1700
0	5.23	10.46	15.68	20.9	26.1	31.4	36.6	41.8	47.0	57.5	62.7	67.9	73.2	78.4	83.6	88.8
1	5.26	10.51	15.77	21.0	26.3	31.5	36.8	42.0	47.3	57.8	63.1	68.3	73.6	78.8	84.1	89.3
2	5.29	10.57	15.85	21.1	26.4	31.7	37.0	42.3	47.6	58.1	63.4	68.7	74.0	79.3	84.6	89.8
3	5.31	10.63	15.94	21.3	26.6	31.9	37.2	42.5	47.8	58.4	63.8	69.1	74.4	79.7	85.0	90.4
4	5.34	10.68	16.03	21.4	26.7	32.0	37.4	42.7	48.1	58.7	64.1	69.4	74.8	80.1	85.5	90.8
5	5.37	10.74	16.11	21.5	26.9	32.2	37.6	43.0	48.3	59.1	64.4	69.8	75.2	80.6	85.9	91.3
6	5.40	10.80	16.20	21.6	27.0	32.4	37.8	43.2	48.6	59.4	64.8	70.2	75.6	81.0	86.4	91.8
7	5.43	10.86	16.29	21.7	27.1	32.6	38.0	43.4	48.9	59.7	65.1	70.6	76.0	81.4	86.9	92.3
8	5.46	10.92	16.37	21.8	27.3	32.7	38.2	43.7	49.1	60.0	65.5	71.0	76.4	81.9	87.3	92.8
9	5.49	10.97	16.46	21.9	27.4	32.9	38.4	43.9	49.4	60.4	65.8	71.3	76.8	82.3	87.8	93.3
10	5.52	11.03	16.55	22.1	27.6	33.1	38.6	44.1	49.6	60.7	66.2	71.7	77.2	82.7	88.2	93.8
11	5.54	11.10	16.63	22.2	27.7	33.3	38.8	44.4	49.9	61.0	66.5	72.1	77.6	83.2	88.7	94.3
12	5.58	11.15	16.72	22.3	27.9	33.4	39.0	44.6	50.2	61.3	66.9	72.5	78.0	83.6	89.2	94.7
13	5.60	11.20	16.81	22.4	28.0	33.6	39.2	44.8	50.4	61.6	67.2	72.8	78.4	84.0	89.6	95.2
14	5.63	11.26	16.89	22.5	28.2	33.8	39.4	45.0	50.7	61.9	67.6	73.2	78.8	84.5	90.1	95.7
15	5.66	11.32	16.98	22.6	28.3	34.0	39.6	45.3	50.9	62.3	67.9	73.6	79.2	84.9	90.6	96.2
16	5.69	11.38	17.07	22.8	28.4	34.1	39.8	45.5	51.2	62.6	68.3	74.0	79.6	85.3	91.0	96.7
17	5.72	11.44	17.15	22.9	28.6	34.3	40.0	45.7	51.5	62.9	68.6	74.3	80.0	85.8	91.5	97.2
18	5.75	11.49	17.24	23.0	28.7	34.5	40.2	46.0	51.7	63.2	69.0	74.7	80.5	86.2	92.0	97.7
19	5.77	11.55	17.33	23.1	28.9	34.7	40.4	46.2	52.0	63.5	69.3	75.1	80.9	86.6	92.4	98.2
20	5.80	11.61	17.41	23.2	29.0	34.8	40.6	46.4	52.2	63.8	69.6	75.5	81.3	87.1	92.9	98.7
21	5.83	11.67	17.50	23.3	29.2	35.0	40.8	46.7	52.5	64.2	70.0	75.8	81.7	87.5	93.3	99.2
22	5.86	11.72	17.59	23.4	29.3	35.2	41.0	46.9	52.8	64.5	70.4	76.2	82.1	87.9	93.8	99.7
23	5.89	11.78	17.67	23.6	29.5	35.3	41.2	47.1	53.0	64.8	70.7	76.6	82.5	88.4	94.3	100.2
24	5.92	11.84	17.76	23.7	29.6	35.5	41.4	47.4	53.3	65.1	71.0	77.0	82.9	88.8	94.7	100.6
25	5.95	11.90	17.85	23.8	29.7	35.7	41.6	47.6	53.5	65.4	71.4	77.3	83.3	89.2	95.2	101.1
26	5.98	11.96	17.93	23.9	29.9	35.9	41.8	47.8	53.8	65.8	71.7	77.7	83.7	89.7	95.6	101.6
27	6.01	12.01	18.02	24.0	30.0	36.0	42.0	48.1	54.1	66.1	72.1	78.1	84.1	90.1	96.1	102.1
28	6.04	12.07	18.11	24.1	30.2	36.2	42.2	48.3	54.3	66.4	72.4	78.5	84.5	90.5	96.6	102.6
29	6.06	12.13	18.19	24.3	30.3	36.4	42.4	48.5	54.6	66.7	72.8	78.8	84.9	91.0	97.0	103.1
30	6.09	12.19	18.28	24.4	30.5	36.6	42.7	48.7	54.8	67.0	73.1	79.2	85.3	91.4	97.5	103.6
31	6.12	12.24	18.37	24.5	30.6	36.7	42.9	49.0	55.1	67.3	73.5	79.6	85.7	91.8	98.0	104.1
32	6.15	12.30	18.45	24.6	30.8	36.9	43.1	49.2	55.4	67.7	73.8	80.0	86.1	92.3	98.4	104.6
33	6.18	12.36	18.54	24.7	30.9	37.1	43.3	49.4	55.6	68.0	74.2	80.3	86.5	92.7	98.9	105.1
34	6.21	12.42	18.63	24.8	31.0	37.2	43.5	49.7	55.9	68.3	74.5	80.7	86.9	93.1	99.3	105.6
35	6.24	12.48	18.71	25.0	31.2	37.4	43.7	49.9	56.1	68.6	74.9	81.1	87.3	93.6	99.8	106.0
36	6.27	12.53	18.80	25.1	31.3	37.6	43.9	50.1	56.4	68.9	75.2	81.5	87.7	94.0	100.3	106.5
37	6.30	12.59	18.89	25.2	31.5	37.8	44.1	50.4	56.7	69.2	75.5	81.8	88.1	94.4	100.7	107.0
38	6.32	12.65	18.97	25.3	31.6	37.9	44.3	50.6	56.9	69.6	75.9	82.2	88.5	94.8	101.2	107.5
39	6.35	12.71	19.06	25.4	31.8	38.1	44.5	50.8	57.2	69.9	76.2	82.6	88.9	95.3	101.6	108.0
40	6.38	12.76	19.15	25.5	31.9	38.3	44.7	51.1	57.4	70.2	76.6	83.0	89.4	95.7	102.1	108.5
41	6.41	12.82	19.23	25.6	32.1	38.5	44.9	51.3	57.7	70.5	76.9	83.3	89.7	96.2	102.6	109.0
42	6.44	12.88	19.32	25.8	32.2	38.6	45.1	51.5	58.0	70.8	77.3	83.7	90.2	96.6	103.0	109.5
43	6.47	12.94	19.41	25.9	32.3	38.8	45.3	51.7	58.2	71.1	77.6	84.1	90.6	97.0	103.5	110.0
44	6.50	13.00	19.49	26.0	32.5	39.0	45.5	52.0	58.5	71.5	78.0	84.5	91.0	97.5	104.0	110.5
45	6.53	13.05	19.58	26.1	32.6	39.2	45.7	52.2	58.7	71.8	78.3	84.8	91.4	97.9	104.4	110.9
46	6.56	13.11	19.66	26.2	32.8	39.3	45.9	52.4	59.0	72.1	78.7	85.2	91.8	98.3	104.9	111.4
47	6.59	13.17	19.75	26.3	32.9	39.5	46.1	52.7	59.3	72.4	79.0	85.6	92.2	98.8	105.3	111.9
48	6.61	13.23	19.84	26.4	33.1	39.7	46.3	52.9	59.5	72.7	79.4	86.0	92.6	99.2	105.8	112.4
49	6.64	13.28	19.92	26.6	33.2	39.8	46.5	53.1	59.8	73.1	79.7	86.3	93.0	99.6	106.3	112.9
50	6.67	13.34	20.01	26.7	33.4	40.0	46.7	53.4	60.0	73.4	80.0	86.7	93.4	100.1	106.7	113.4
51	6.70	13.40	20.10	26.8	33.5	40.2	46.9	53.6	60.3	73.7	80.4	87.1	93.8	100.5	107.2	113.9
52	6.73	13.46	20.18	26.9	33.6	40.4	47.1	53.8	60.6	74.0	80.7	87.5	94.2	100.9	107.6	114.4
53	6.76	13.51	20.27	27.0	33.8	40.5	47.3	54.1	60.8	74.3	81.1	87.8	94.6	101.4	108.1	114.9
54	6.79	13.57	20.36	27.1	33.9	40.7	47.5	54.3	61.1	74.6	81.4	88.2	95.0	101.8	108.6	115.4
55	6.81	13.63	20.44	27.3	34.1	40.9	47.7	54.5	61.3	75.0	81.8	88.6	95.4	102.2	109.0	115.8
56	6.85	13.69	20.53	27.4	34.2	41.1	47.9	54.7	61.6	75.3	82.1	89.0	95.8	102.6	109.5	116.3
57	6.88	13.74	20.62	27.5	34.4	41.2	48.1	55.0	61.8	75.6	82.5	89.3	96.2	103.1	109.9	116.8
58	6.90	13.80	20.70	27.6	34.5	41.4	48.3	55.2	62.1	75.9	82.8	89.7	96.6	103.5	110.4	117.3
59	6.93	13.86	20.79	27.7	34.6	41.6	48.5	55.4	62.4	76.2	83.2	90.1	97.0	104.0	110.9	117.8
Horz. Dist.	99.63	199.3	298.9	398.5	498.2	598	697	797	897	1096	1196	1295	1395	1494	1594	1694

TABLE III.—(*Continued*)

3°

1800	1900	2100	2200	2300	2400	2500	2600	2700	2800	2900	3100	3200	3300	3400	3500	′
94.1	99.3	109.8	115.0	120.2	125.4	130.7	135.9	141.1	146.3	151.6	162.0	167.2	172.5	177.7	182.9	0
94.6	99.9	110.4	115.6	120.9	126.1	131.4	136.6	141.9	147.2	152.4	162.9	168.2	173.4	178.7	183.9	1
95.1	100.4	111.0	116.3	121.5	126.8	132.1	137.4	142.7	148.0	153.2	163.8	169.1	174.4	179.7	185.0	2
95.6	100.9	111.6	116.9	122.2	127.5	132.8	138.1	143.4	148.8	154.1	164.7	170.0	175.3	180.6	186.0	3
96.2	101.5	112.2	117.5	122.9	128.2	133.6	138.9	144.2	149.6	154.9	165.6	170.9	176.3	181.6	187.0	4
96.7	102.0	112.8	118.2	123.5	128.9	134.3	139.6	145.0	150.4	155.8	166.5	171.9	177.2	182.6	188.0	5
97.2	102.6	113.4	118.8	124.2	129.6	135.0	140.4	145.8	151.2	156.6	167.4	172.8	178.2	183.6	189.0	6
97.7	103.2	114.0	119.4	124.9	130.3	135.7	141.2	146.6	152.0	157.4	168.3	173.7	179.2	184.6	190.0	7
98.2	103.7	114.6	120.1	125.5	131.0	136.4	141.9	147.4	152.8	158.3	169.2	174.7	180.1	185.6	191.0	8
98.8	104.2	115.2	120.7	126.2	131.7	137.2	142.6	148.1	153.6	159.1	170.1	175.6	181.0	186.5	192.0	9
99.3	104.9	115.8	121.3	126.9	132.4	137.9	143.4	148.9	154.4	159.9	171.0	176.5	182.0	187.5	193.0	10
99.8	105.3	116.4	122.0	127.5	133.1	138.6	144.2	149.7	155.2	160.8	171.9	177.4	183.0	188.5	194.1	11
100.3	105.9	117.0	122.6	128.2	133.8	139.3	144.9	150.5	156.1	161.6	172.8	178.4	183.9	189.5	195.1	12
100.8	106.4	117.6	123.3	128.9	134.5	140.1	145.7	151.3	156.9	162.5	173.7	179.3	184.9	190.5	196.1	13
101.4	107.0	118.3	123.9	129.5	135.2	140.8	146.4	152.0	157.7	163.3	174.6	180.2	185.8	191.5	197.1	14
101.9	107.5	118.9	124.5	130.2	135.8	141.5	147.2	152.8	158.6	164.1	175.5	181.1	186.8	192.4	198.1	15
102.4	108.1	119.5	125.2	130.8	136.5	142.2	147.9	153.6	159.3	165.0	176.4	182.0	187.7	193.4	199.1	16
102.9	108.6	120.1	125.8	131.5	137.2	143.0	148.7	154.4	160.1	165.8	177.3	183.0	188.7	194.4	200.1	17
103.4	109.2	120.7	126.4	132.2	137.9	143.7	149.4	155.2	160.9	166.7	178.2	183.9	189.6	195.4	201.1	18
104.0	109.7	121.3	127.1	132.9	138.6	144.4	150.2	156.0	161.7	167.5	179.1	184.8	190.6	196.4	202.2	19
104.4	110.3	121.9	127.7	133.5	139.3	145.1	150.9	156.7	162.5	168.3	179.9	185.7	191.5	197.4	203.2	20
105.0	110.8	122.5	128.3	134.2	140.0	145.8	151.7	157.5	163.3	169.2	180.8	186.7	192.5	198.3	204.2	21
105.5	111.4	123.1	129.0	134.9	140.7	146.6	152.4	158.3	164.2	170.0	181.7	187.6	193.5	199.3	205.2	22
106.0	111.9	123.7	129.6	135.5	141.4	147.3	153.2	159.1	165.0	170.8	182.6	188.5	194.4	200.3	206.2	23
106.6	112.5	124.3	130.2	136.2	142.1	148.0	153.9	159.8	165.8	171.7	183.5	189.4	195.4	201.3	207.2	24
107.1	113.0	124.9	130.9	136.8	142.7	148.7	154.7	160.6	166.6	172.5	184.4	190.4	196.3	202.3	208.2	25
107.6	113.6	125.5	131.5	137.5	143.5	149.4	155.4	161.4	167.4	173.4	185.3	191.3	197.3	203.3	209.2	26
108.1	114.1	126.1	132.2	138.2	144.2	150.2	156.2	162.2	168.2	174.2	186.2	192.2	198.2	204.2	210.2	27
108.6	114.7	126.7	132.8	138.8	144.8	150.9	156.9	163.0	169.0	175.0	187.1	193.1	199.2	205.2	211.2	28
109.2	115.2	127.4	133.4	139.5	145.5	151.6	157.7	163.7	169.9	175.9	188.0	194.1	200.1	206.2	212.3	29
109.7	115.8	128.0	134.1	140.2	146.2	152.3	158.4	164.5	170.6	176.8	188.9	195.0	201.1	207.2	213.3	30
110.2	116.3	128.6	134.7	140.8	146.9	153.1	159.2	165.3	171.4	177.6	189.8	195.9	202.0	208.2	214.3	31
110.7	116.9	129.2	135.3	141.5	147.6	153.8	159.9	166.1	172.2	178.4	190.7	196.8	203.0	209.1	215.3	32
111.2	117.4	129.8	136.0	142.1	148.3	154.5	160.7	166.9	173.0	179.2	191.6	197.8	203.9	210.1	216.3	33
111.8	118.0	130.4	136.6	142.8	149.0	155.2	161.4	167.6	173.8	180.1	192.5	198.7	204.9	211.1	217.3	34
112.3	118.5	131.0	137.2	143.5	149.7	156.0	162.2	168.4	174.7	180.9	193.4	199.6	205.8	212.1	218.3	35
112.8	119.1	131.6	137.9	144.1	150.4	156.7	162.9	169.2	175.5	181.8	194.3	200.5	206.8	213.1	219.3	36
113.3	119.6	132.2	138.5	144.8	151.1	157.4	163.7	170.0	176.3	182.6	195.2	201.5	207.8	214.0	220.3	37
113.8	120.2	132.8	139.1	145.5	151.8	158.1	164.4	170.8	177.1	183.4	196.1	202.4	208.7	215.0	221.4	38
114.4	120.7	133.4	139.8	146.1	152.5	158.8	165.2	171.6	177.9	184.2	196.9	203.3	209.6	216.0	222.4	39
114.9	121.3	134.0	140.4	146.8	153.2	159.6	165.9	172.3	178.7	185.1	197.8	204.2	210.6	217.0	223.4	40
115.4	121.8	134.6	141.0	147.4	153.9	160.3	166.7	173.1	179.5	185.9	198.7	205.1	211.6	218.0	224.4	41
115.9	122.4	135.2	141.7	148.1	154.6	161.0	167.4	173.9	180.3	186.8	199.6	206.1	212.5	219.0	225.4	42
116.4	122.9	135.8	142.3	148.8	155.2	161.7	168.2	174.6	181.1	187.6	200.5	207.0	213.5	219.9	226.4	43
117.0	123.5	136.4	142.9	149.4	155.9	162.4	168.9	175.4	181.9	188.4	201.4	207.9	214.4	220.9	227.4	44
117.5	124.0	137.1	143.6	150.1	156.6	163.2	169.7	176.2	182.7	189.3	202.3	208.8	215.4	221.9	228.4	45
118.0	124.5	137.7	144.2	150.8	157.3	163.9	170.4	177.0	183.5	190.1	203.2	209.8	216.3	222.9	229.4	46
118.5	125.1	138.3	144.8	151.4	158.0	164.6	171.2	177.8	184.4	190.9	204.1	210.7	217.3	223.9	230.4	47
119.0	125.6	138.9	145.5	152.1	158.7	165.3	171.9	178.6	185.2	191.8	205.0	211.6	218.2	224.8	231.5	48
119.5	126.2	139.5	146.1	152.7	159.4	166.0	172.7	179.3	186.0	192.6	205.9	212.5	219.2	225.8	232.5	49
120.1	126.7	140.1	146.8	153.4	160.1	166.8	173.4	180.1	186.8	193.4	206.8	213.5	220.1	226.8	233.5	50
120.6	127.3	140.7	147.4	154.1	160.8	167.5	174.2	180.9	187.6	194.3	207.7	214.4	221.1	227.8	234.5	51
121.1	127.8	141.3	148.0	154.7	161.5	168.2	174.9	181.7	188.4	195.1	208.6	215.3	222.0	228.8	235.5	52
121.6	128.4	141.9	148.6	155.4	162.2	168.9	175.7	182.4	189.2	195.9	209.5	216.2	223.0	229.7	236.5	53
122.1	128.9	142.5	149.3	156.1	162.9	169.6	176.4	183.2	190.0	196.8	210.4	217.1	223.9	230.7	237.5	54
122.7	129.5	143.1	149.9	156.7	163.5	170.4	177.2	184.0	190.8	197.6	211.2	218.1	224.9	231.7	238.5	55
123.2	130.0	143.7	150.6	157.4	164.2	171.1	177.9	184.8	191.6	198.5	212.1	219.0	225.8	232.7	239.5	56
123.7	130.6	144.3	151.2	158.1	164.9	171.8	178.7	185.5	192.4	199.3	213.0	219.9	226.8	233.6	240.5	57
124.2	131.1	144.9	151.8	158.7	165.6	172.5	179.4	186.3	193.2	200.1	213.9	220.8	227.7	234.6	241.5	58
124.7	131.7	145.5	152.5	159.4	166.3	173.3	180.2	187.1	194.0	201.0	214.8	221.8	228.7	235.6	242.6	59
1793	1893	2092	2192	2291	2391	2491	2590	2690	2790	2889	3088	3188	3288	3387	3487	Horz. Dist.

4°

′	100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	1700
0	6.96	13.92	20.87	27.8	34.8	41.8	48.7	55.7	62.6	76.5	83.5	90.5	97.4	104.4	111.3	118.3
1	6.99	13.98	20.96	28.0	34.9	41.9	48.9	55.9	62.9	76.9	83.8	90.8	97.8	104.8	111.8	118.8
2	7.02	14.03	21.05	28.1	35.1	42.1	49.1	56.1	63.1	77.2	84.2	91.2	98.2	105.2	112.3	119.3
3	7.05	14.09	21.14	28.2	35.2	42.3	49.3	56.4	63.4	77.5	84.5	91.6	98.6	105.7	112.7	119.8
4	7.08	14.15	21.22	28.3	35.4	42.4	49.5	56.6	63.7	77.8	84.9	92.0	99.0	106.1	113.2	120.3
5	7.10	14.21	21.31	28.4	35.5	42.6	49.7	56.8	63.9	78.1	85.2	92.3	99.4	106.5	113.6	120.7
6	7.13	14.26	21.39	28.5	35.7	42.8	49.9	57.1	64.2	78.4	85.6	92.7	99.8	107.0	114.1	121.2
7	7.16	14.32	21.48	28.6	35.8	43.0	50.1	57.3	64.4	78.8	85.9	93.1	100.2	107.4	114.6	121.7
8	7.19	14.38	21.57	28.8	35.9	43.1	50.3	57.5	64.7	79.1	86.3	93.5	100.6	107.8	115.0	122.2
9	7.22	14.44	21.65	28.9	36.1	43.3	50.5	57.7	65.0	79.4	86.6	93.8	101.0	108.3	115.5	122.7
10	7.25	14.49	21.74	29.0	36.2	43.5	50.7	58.0	65.2	79.7	87.0	94.2	101.5	108.7	115.9	123.2
11	7.28	14.55	21.83	29.1	36.4	43.7	50.9	58.2	65.5	80.0	87.3	94.6	101.9	109.1	116.4	123.7
12	7.30	14.61	21.91	29.2	36.5	43.8	51.1	58.4	65.7	80.3	87.6	95.0	102.3	109.6	116.9	124.2
13	7.33	14.67	22.00	29.3	36.7	44.0	51.3	58.7	66.0	80.7	88.0	95.3	102.7	110.0	117.3	124.7
14	7.36	14.72	22.08	29.4	36.8	44.2	51.5	58.9	66.3	81.0	88.3	95.7	103.1	110.4	117.8	125.1
15	7.39	14.78	22.17	29.6	37.0	44.3	51.7	59.1	66.5	81.3	88.7	96.1	103.5	110.9	118.2	125.6
16	7.42	14.84	22.26	29.7	37.1	44.5	51.9	59.4	66.8	81.6	89.0	96.4	103.9	111.3	118.7	126.1
17	7.45	14.90	22.34	29.8	37.2	44.7	52.1	59.6	67.0	81.9	89.4	96.8	104.3	111.7	119.2	126.6
18	7.48	14.95	22.43	29.9	37.4	44.9	52.3	59.8	67.3	82.2	89.7	97.2	104.7	112.2	119.6	127.1
19	7.51	15.01	22.52	30.0	37.5	45.0	52.5	60.0	67.5	82.6	90.1	97.6	105.1	112.6	120.1	127.6
20	7.53	15.07	22.60	30.1	37.7	45.2	52.7	60.3	67.8	82.9	90.4	97.9	105.5	113.0	120.6	128.1
21	7.56	15.13	22.69	30.3	37.8	45.4	52.9	60.5	68.1	83.2	90.8	98.3	105.9	113.4	121.0	128.6
22	7.59	15.18	22.78	30.4	38.0	45.6	53.1	60.7	68.3	83.5	91.1	98.7	106.3	113.9	121.5	129.1
23	7.62	15.24	22.86	30.5	38.1	45.7	53.3	61.0	68.6	83.8	91.4	99.1	106.7	114.3	121.9	129.5
24	7.65	15.30	22.95	30.6	38.2	45.9	53.5	61.2	68.8	84.1	91.8	99.4	107.1	114.7	122.4	130.0
25	7.68	15.36	23.03	30.7	38.4	46.1	53.7	61.4	69.1	84.5	92.1	99.8	107.5	115.2	122.8	130.5
26	7.71	15.41	23.12	30.8	38.5	46.2	53.9	61.7	69.4	84.8	92.5	100.2	107.9	115.6	123.3	131.0
27	7.74	15.47	23.21	30.9	38.7	46.4	54.1	61.9	69.6	85.1	92.8	100.6	108.3	116.0	123.8	131.5
28	7.76	15.53	23.29	31.1	38.8	46.6	54.4	62.1	69.9	85.4	93.2	100.9	108.7	116.5	124.2	132.0
29	7.79	15.59	23.38	31.2	39.0	46.8	54.6	62.3	70.1	85.7	93.5	101.3	109.1	116.9	124.7	132.5
30	7.82	15.64	23.46	31.3	39.1	46.9	54.8	62.6	70.4	86.0	93.9	101.7	109.5	117.3	125.1	133.0
31	7.85	15.70	23.55	31.4	39.3	47.1	55.0	62.8	70.7	86.4	94.2	102.1	109.9	117.8	125.6	133.5
32	7.88	15.76	23.64	31.5	39.4	47.3	55.2	63.0	70.9	86.7	94.5	102.4	110.3	118.2	126.1	133.9
33	7.91	15.82	23.72	31.6	39.5	47.4	55.4	63.3	71.2	87.0	94.9	102.8	110.7	118.6	126.5	134.4
34	7.94	15.87	23.81	31.7	39.7	47.6	55.6	63.5	71.4	87.3	95.2	103.2	111.1	119.0	127.0	134.9
35	7.97	15.93	23.90	31.9	39.8	47.8	55.8	63.7	71.7	87.6	95.6	103.6	111.5	119.5	127.4	135.4
36	7.99	15.99	23.98	32.0	40.0	48.0	56.0	64.0	71.9	87.9	95.9	103.9	111.9	119.9	127.9	135.9
37	8.02	16.05	24.07	32.1	40.1	48.1	56.2	64.2	72.2	88.2	96.3	104.3	112.3	120.3	128.4	136.4
38	8.05	16.10	24.15	32.2	40.3	48.3	56.4	64.4	72.5	88.6	96.6	104.7	112.7	120.8	128.8	136.9
39	8.08	16.16	24.24	32.3	40.4	48.5	56.6	64.6	72.7	88.9	97.0	105.0	113.1	121.2	129.3	137.4
40	8.11	16.22	24.33	32.4	40.5	48.7	56.8	64.9	73.0	89.2	97.3	105.4	113.5	121.6	129.7	137.9
41	8.14	16.27	24.41	32.6	40.7	48.8	57.0	65.1	73.2	89.5	97.7	105.8	113.9	122.1	130.2	138.3
42	8.17	16.33	24.50	32.7	40.8	49.0	57.2	65.3	73.5	89.8	98.0	106.2	114.3	122.5	130.7	138.8
43	8.20	16.39	24.58	32.8	41.0	49.2	57.4	65.6	73.8	90.1	98.3	106.5	114.7	122.9	131.1	139.3
44	8.22	16.45	24.67	32.9	41.1	49.3	57.6	65.8	74.0	90.5	98.7	106.9	115.1	123.4	131.6	139.8
45	8.25	16.50	24.76	33.0	41.3	49.5	57.8	66.0	74.3	90.8	99.0	107.3	115.5	123.8	132.0	140.3
46	8.28	16.56	24.84	33.1	41.4	49.7	58.0	66.2	74.5	91.1	99.4	107.7	115.9	124.2	132.5	140.8
47	8.31	16.62	24.93	33.2	41.6	49.9	58.2	66.5	74.8	91.4	99.7	108.0	116.3	124.7	133.9	141.3
48	8.34	16.68	25.02	33.4	41.7	50.0	58.4	66.7	75.0	91.7	100.1	108.4	116.7	125.1	133.4	141.8
49	8.37	16.73	25.10	33.5	41.8	50.2	58.6	66.9	75.3	92.0	100.4	108.8	117.1	125.5	133.9	142.2
50	8.40	16.79	25.19	33.6	42.0	50.4	58.8	67.2	75.6	92.4	100.8	109.1	117.5	125.9	134.3	142.7
51	8.43	16.85	25.27	33.7	42.1	50.5	59.0	67.4	75.8	92.7	101.1	109.5	117.9	126.4	134.8	143.2
52	8.45	16.91	25.36	35.8	42.3	50.7	59.2	67.6	76.1	93.0	101.4	109.9	118.3	126.8	135.2	143.7
53	8.48	16.96	25.45	33.9	42.4	50.9	59.4	67.9	76.3	93.3	101.8	110.3	118.7	127.2	135.7	144.2
54	8.51	17.02	25.53	34.0	42.6	51.1	59.6	68.1	76.6	93.6	102.1	110.6	119.1	127.7	136.2	144.7
55	8.54	17.08	25.62	34.2	42.7	51.2	59.8	68.3	76.9	94.9	102.5	111.0	119.5	128.1	136.6	145.2
56	8.57	17.14	25.70	34.3	42.8	51.4	60.0	68.5	77.1	94.2	102.8	111.4	120.0	128.5	137.1	145.7
57	8.60	17.19	25.79	34.4	43.0	51.6	60.2	68.8	77.4	94.6	103.2	111.8	120.4	128.9	137.5	146.1
58	8.63	17.26	25.87	34.5	43.1	51.8	60.4	69.0	77.6	94.9	103.5	112.1	120.8	129.4	138.0	146.6
59	8.65	17.31	25.96	34.6	43.3	51.9	60.6	69.2	77.9	95.2	103.8	112.5	121.2	129.8	138.5	147.1
Horz. Dist.	99.38	198.8	298.1	397.5	496.9	596	696	795	894	1093	1193	1292	1391	1491	1590	1689

TABLE III.—(*Continued*)

4°

1800	1900	2100	2200	2300	2400	2500	2600	2700	2800	2900	3100	3200	3300	3400	3500	′
125.2	132.2	146.1	153.1	160.0	167.0	174.0	180.9	187.9	194.8	201.8	215.7	222.7	229.6	236.6	243.5	0
125.8	132.8	146.7	153.7	160.7	167.7	174.7	181.7	188.7	195.6	202.6	216.6	223.6	230.6	237.6	244.6	1
126.3	133.3	147.3	154.4	161.4	168.4	175.4	182.4	189.4	196.5	203.5	217.5	224.5	231.5	238.6	245.6	2
126.8	133.9	147.9	155.0	162.0	169.1	176.1	183.2	190.2	197.3	204.3	218.4	225.4	232.5	239.5	246.6	3
127.3	134.4	148.6	155.6	162.7	169.8	176.8	183.9	191.0	198.1	205.1	219.3	226.4	233.4	240.5	247.6	4
127.8	134.9	149.2	156.3	163.4	170.5	177.6	184.7	191.8	198.9	206.0	220.2	227.3	234.4	241.5	248.6	5
128.4	135.5	149.8	156.9	164.0	171.2	178.3	185.4	192.6	199.7	206.8	221.1	228.2	235.3	242.5	249.6	6
128.9	136.0	150.4	157.5	164.7	171.8	179.0	186.2	193.3	200.5	207.6	222.0	229.1	236.3	243.4	250.6	7
129.4	136.6	151.0	158.2	165.3	172.5	179.7	186.9	194.1	201.3	208.5	222.9	230.0	237.2	244.4	251.6	8
129.9	137.1	151.6	158.8	166.0	173.2	180.4	187.7	194.9	202.1	209.3	223.8	231.0	238.2	245.4	252.6	9
130.4	137.7	152.2	159.4	166.7	173.9	181.2	188.4	195.7	202.9	210.1	224.6	231.9	239.1	246.4	253.6	10
131.0	138.2	152.8	160.1	167.3	174.6	181.9	189.2	196.4	203.7	211.0	225.5	232.8	240.1	247.4	254.6	11
131.5	138.8	153.4	160.7	168.0	175.3	182.6	189.9	197.2	204.5	211.8	226.4	233.7	241.0	248.3	255.6	12
132.0	139.3	154.0	161.3	168.7	176.0	183.3	190.7	198.0	205.3	212.7	227.3	234.7	242.9	249.3	256.6	13
132.5	139.9	154.6	162.0	169.3	176.7	184.0	191.4	198.8	206.1	213.5	228.2	235.6	242.9	250.3	257.7	14
133.0	140.4	155.2	162.6	170.0	177.4	184.7	192.2	199.5	206.9	214.3	229.1	236.5	243.9	251.3	258.7	15
133.5	141.0	155.8	163.2	170.6	178.1	185.5	192.9	200.3	207.7	215.2	230.0	237.4	244.8	252.2	259.7	16
134.1	141.5	156.4	163.9	171.3	178.8	186.2	193.6	201.1	208.5	216.0	230.9	238.3	245.8	253.2	260.7	17
134.6	142.1	157.0	164.5	172.9	179.4	186.9	194.4	201.9	209.3	216.8	231.8	239.3	246.7	254.2	261.7	18
135.1	142.6	157.6	165.1	172.6	180.1	187.6	195.1	202.6	210.2	217.7	232.7	240.2	247.7	255.2	262.7	19
135.6	143.2	158.2	165.8	173.3	180.8	188.4	195.9	203.4	211.0	218.5	233.6	241.1	248.6	256.2	263.7	20
136.1	143.7	158.8	166.4	173.9	181.5	189.1	196.6	204.2	211.8	219.3	234.5	242.0	249.6	257.1	264.7	21
136.7	144.2	159.4	167.0	174.6	182.2	189.8	197.4	205.0	212.6	220.2	235.4	242.9	250.5	258.1	265.7	22
137.2	144.8	160.0	167.6	175.3	182.9	190.5	198.1	205.8	213.4	221.0	236.2	243.9	251.5	259.1	266.7	23
137.7	145.3	160.6	168.3	175.9	183.6	191.2	198.9	206.5	214.2	221.8	237.1	244.8	252.4	260.1	267.7	24
138.2	145.9	161.2	168.9	176.6	184.3	192.0	199.6	207.3	215.1	222.7	238.0	245.7	253.4	261.1	268.7	25
138.7	146.4	161.8	169.6	177.3	185.0	192.7	200.4	208.1	215.8	223.5	238.9	246.6	254.3	262.0	269.7	26
139.2	147.0	162.4	170.2	177.9	185.7	193.4	201.1	208.9	216.6	224.3	239.8	247.5	255.3	263.0	270.7	27
139.8	147.5	163.1	170.8	178.6	186.3	194.1	201.9	209.6	217.4	225.2	240.7	248.5	256.2	264.0	271.8	28
140.3	148.1	163.7	171.4	179.2	187.0	194.8	202.6	210.4	218.2	226.0	241.6	240.4	257.2	265.0	272.8	29
140.8	148.6	164.3	172.1	179.9	187.7	195.5	203.4	211.2	219.0	226.8	242.5	250.3	258.1	265.9	273.8	30
141.3	149.2	164.9	172.7	180.6	188.4	196.3	204.1	212.0	219.8	227.7	243.4	251.2	259.1	266.9	274.8	31
141.8	149.7	165.5	173.3	181.2	189.1	197.0	204.9	212.7	220.6	228.5	244.2	252.1	260.0	267.9	275.8	32
142.3	150.3	166.1	174.0	181.9	189.8	197.7	205.6	213.5	221.4	229.3	245.1	253.1	261.0	268.9	276.8	33
142.9	150.8	166.7	174.6	182.5	190.5	198.4	206.3	214.3	222.2	230.2	246.0	254.0	261.9	269.8	277.8	34
143.4	151.3	167.3	175.2	183.2	191.2	199.1	207.1	215.1	223.0	231.0	246.9	254.9	262.9	270.8	278.8	35
143.9	151.9	167.9	175.9	183.9	191.9	199.8	207.8	215.8	223.8	231.8	247.8	255.8	263.8	271.8	279.8	36
144.4	152.4	168.5	176.5	184.5	192.6	200.6	208.6	216.6	224.6	232.7	248.7	256.7	264.7	272.8	280.8	37
144.9	153.0	169.1	177.1	185.2	193.2	201.3	209.3	217.4	225.4	233.5	249.6	257.6	265.7	273.8	281.8	38
145.4	153.5	169.7	177.8	185.8	193.9	202.0	210.1	218.2	226.2	234.3	250.5	258.6	266.6	274.7	282.8	39
145.9	154.1	170.3	178.4	186.5	194.6	202.7	210.8	218.9	227.1	235.2	251.4	259.5	267.6	275.7	283.8	40
146.5	154.6	170.9	179.0	187.2	195.3	203.4	211.6	219.7	227.9	236.0	252.3	260.4	268.5	276.7	284.8	41
147.0	155.2	171.5	179.7	187.8	196.0	204.2	212.3	220.5	228.7	236.8	253.2	261.3	269.5	277.7	285.8	42
147.5	155.7	172.1	180.3	188.5	196.7	204.9	213.1	221.3	229.5	237.7	254.0	262.2	270.4	278.6	286.8	43
148.0	156.2	172.7	180.9	189.1	197.4	205.6	213.8	222.0	230.3	238.5	254.9	263.2	271.4	279.6	287.8	44
148.5	156.8	173.3	181.6	189.8	198.1	206.3	214.6	222.8	231.1	239.3	255.8	264.1	272.3	280.6	288.8	45
149.1	157.3	173.9	182.2	190.5	198.7	207.0	215.3	223.6	231.9	240.1	256.7	265.0	273.3	281.6	289.8	46
149.6	157.9	174.5	182.8	191.1	199.4	207.8	216.1	224.4	232.7	241.0	257.6	265.9	274.2	282.5	290.8	47
150.1	158.4	175.1	183.4	191.8	200.1	208.5	216.8	225.1	233.5	241.8	258.5	266.8	275.2	283.5	291.8	48
150.6	159.0	175.7	184.1	192.4	200.8	209.2	217.5	225.9	234.3	242.6	259.4	267.7	276.1	284.5	292.8	49
151.1	159.5	176.3	184.7	193.1	201.5	209.9	218.3	226.7	235.1	243.5	260.3	268.7	277.1	285.5	293.9	50
151.6	160.1	176.9	185.3	193.8	202.2	210.6	219.0	227.5	235.9	244.3	261.2	269.6	278.0	286.4	294.9	51
152.2	160.6	177.5	186.0	194.4	202.9	211.3	219.8	228.2	236.7	245.1	262.0	270.5	278.9	287.4	295.9	52
152.7	161.2	178.1	186.6	195.1	203.6	212.0	220.5	229.0	237.5	246.0	262.9	271.4	279.9	288.4	296.9	53
153.2	161.7	178.7	187.2	195.7	204.2	212.8	221.3	229.8	238.3	246.8	263.8	272.3	280.8	289.4	297.9	54
153.7	162.2	179.3	187.9	196.4	204.9	213.5	222.0	230.6	239.1	247.6	264.7	273.2	281.8	290.3	298.9	55
154.2	162.8	179.9	188.5	197.1	205.6	214.2	222.8	231.3	239.9	248.5	265.6	274.2	282.7	291.3	299.9	56
154.7	163.3	180.5	189.1	197.7	206.3	214.9	223.5	232.1	240.7	249.3	266.5	275.1	283.7	292.3	300.9	57
155.2	163.9	181.1	189.8	198.4	207.0	215.6	224.3	232.9	241.5	250.1	267.4	276.0	284.6	293.2	301.9	58
155.8	164.4	181.7	190.4	199.0	207.7	216.4	225.0	233.7	242.3	251.0	268.3	276.9	285.6	294.2	302.9	59
1789	1888	2087	2186	2286	2385	2484	2584	2683	2783	2882	3081	3180	3279	3379	3478	Horz. Dist.

TABLE III.—(*Continued*)

5°

′	100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	1700
0	8.68	17.36	26.05	34.7	43.4	52.1	60.8	69.5	78.1	95.5	104.2	112.9	121.6	130.2	138.9	147.6
1	8.71	17.42	26.13	34.8	43.6	52.3	61.0	69.7	78.4	95.8	104.5	113.2	122.0	130.7	139.4	148.1
2	8.74	17.48	26.22	35.0	43.7	52.4	61.2	69.9	78.7	96.1	104.9	113.6	122.4	131.1	139.8	148.6
3	8.77	17.54	26.31	35.1	43.8	52.6	61.4	70.1	78.9	96.4	105.2	114.0	122.8	131.5	140.3	149.1
4	8.80	17.59	26.39	35.2	44.0	52.8	61.6	70.4	79.2	96.8	105.6	114.4	123.2	132.0	140.8	149.5
5	8.82	17.65	26.48	35.3	44.1	53.0	61.8	70.6	79.4	97.1	105.9	114.7	123.6	132.4	141.2	150.0
6	8.85	17.71	26.56	35.4	44.3	53.1	62.0	70.8	79.7	97.4	106.2	115.1	124.0	132.8	141.7	150.5
7	8.88	17.77	26.65	35.5	44.4	53.3	62.2	71.1	79.9	97.7	106.6	115.5	124.4	133.2	142.1	151.0
8	8.91	17.82	26.73	35.6	44.5	53.5	62.4	71.3	80.2	98.0	106.9	115.8	124.8	133.7	142.6	151.5
9	8.94	17.88	26.82	35.8	44.7	53.6	62.6	71.5	80.5	98.3	107.3	116.2	125.2	134.1	143.0	152.0
10	8.97	17.94	26.90	35.9	44.8	53.8	62.8	71.8	80.7	98.7	107.6	116.6	125.6	134.5	143.5	152.5
11	9.00	18.00	26.99	36.0	44.9	54.0	63.0	72.0	81.0	99.0	108.0	117.0	126.0	135.0	144.0	153.0
12	9.03	18.05	27.08	36.1	45.1	54.2	63.2	72.2	81.2	99.3	108.3	117.3	126.4	135.4	144.4	153.4
13	9.06	18.11	27.16	36.2	45.3	54.3	63.4	72.4	81.5	99.6	108.7	117.7	126.8	135.8	144.9	153.9
14	9.08	18.17	27.25	36.3	45.4	54.5	63.6	72.7	81.7	99.9	109.0	118.1	127.2	136.2	145.3	154.4
15	9.11	18.22	27.33	36.4	45.6	54.7	63.8	72.9	82.0	100.2	109.3	118.5	127.6	136.7	145.8	154.9
16	9.14	18.28	27.42	36.6	45.7	54.8	64.0	73.1	82.3	100.5	109.7	118.8	127.9	137.1	146.2	155.4
17	9.17	18.34	27.51	36.7	45.8	55.0	64.2	73.4	82.5	100.9	110.0	119.2	128.4	137.5	146.7	155.9
18	9.20	18.39	27.59	36.8	46.0	55.2	64.4	73.6	82.8	101.1	110.4	119.6	128.8	138.0	147.2	156.4
19	9.23	18.45	27.68	36.9	46.1	55.3	64.6	73.8	83.0	101.5	110.7	119.9	129.2	138.4	147.6	156.8
20	9.25	18.51	27.76	37.0	46.3	55.5	64.8	74.0	83.3	101.8	111.0	120.3	129.6	138.8	148.1	157.3
21	9.28	18.57	27.85	37.1	46.4	55.7	65.0	74.3	83.6	102.1	111.4	120.7	130.0	139.3	148.5	157.8
22	9.31	18.62	27.94	37.2	46.6	55.9	65.2	74.5	83.8	102.4	111.7	121.1	130.4	139.7	149.0	158.3
23	9.34	18.68	28.02	37.4	46.7	56.0	65.4	74.7	84.1	102.7	112.1	121.4	130.8	140.1	149.4	158.8
24	9.37	18.74	28.11	37.5	46.8	56.2	65.6	75.0	84.3	103.1	112.4	121.8	131.2	140.5	149.9	159.3
25	9.40	18.80	28.19	37.6	47.0	56.4	65.8	75.2	84.6	103.4	112.8	122.2	131.6	141.0	150.4	159.8
26	9.43	18.85	28.28	37.7	47.1	56.5	66.0	75.4	84.8	103.7	113.1	122.5	132.0	141.4	150.9	160.2
27	9.46	18.91	28.37	37.8	47.3	56.7	66.2	75.6	85.1	104.0	113.5	122.9	132.4	141.9	151.3	160.7
28	9.48	18.97	28.45	37.9	47.4	56.9	66.4	75.9	85.4	104.3	113.8	123.3	132.8	142.3	151.7	161.2
29	9.51	19.02	28.54	38.0	47.6	57.1	66.6	76.1	85.6	104.6	114.1	123.7	133.2	142.7	152.2	161.7
30	9.54	19.08	28.62	38.2	47.7	57.2	66.8	76.3	85.9	104.9	114.5	124.0	133.6	143.1	152.6	162.3
31	9.57	19.14	28.71	38.3	47.8	57.4	67.0	76.6	86.1	105.3	114.8	124.4	134.0	143.6	153.1	162.7
32	9.60	19.20	28.79	38.4	48.0	57.6	67.2	76.8	86.4	105.6	115.2	124.8	134.4	144.0	153.6	163.2
33	9.63	19.25	28.88	38.5	48.1	57.8	67.4	77.0	86.6	105.9	115.5	125.1	134.8	144.4	154.0	163.6
34	9.65	19.31	28.96	38.6	48.3	57.9	67.6	77.2	86.9	106.2	115.9	125.5	135.2	144.8	154.5	164.1
35	9.68	19.37	29.05	38.7	48.4	58.1	67.8	77.5	87.2	106.5	116.2	125.9	135.6	145.3	155.0	164.6
36	9.71	19.42	29.13	38.8	48.6	58.3	68.0	77.7	87.4	106.8	116.5	126.2	136.0	145.7	155.4	165.1
37	9.74	19.48	29.22	39.0	48.7	58.5	68.2	77.9	87.7	107.1	116.9	126.6	136.4	146.1	155.8	165.6
38	9.77	19.54	29.31	39.1	48.9	58.6	68.4	78.2	87.9	107.5	117.2	127.0	136.8	146.5	156.3	166.1
39	9.80	19.60	29.39	39.2	49.0	58.8	68.6	78.4	88.2	107.8	117.6	127.4	137.2	147.0	156.8	166.6
40	9.83	19.65	29.48	39.3	49.2	59.0	68.8	78.6	88.5	108.1	118.0	127.7	137.6	147.4	157.2	167.0
41	9.86	19.71	29.56	39.4	49.3	59.2	69.0	78.8	88.7	108.4	118.3	128.1	138.0	147.8	157.7	167.5
42	9.88	19.77	29.65	39.5	49.4	59.3	69.2	79.1	89.0	108.7	118.6	128.5	138.4	148.2	158.1	168.0
43	9.91	19.81	29.73	39.7	49.6	59.5	69.4	79.3	89.2	109.0	118.9	128.8	138.8	148.7	158.6	168.5
44	9.94	19.88	29.82	39.8	49.7	59.6	69.6	79.5	89.5	109.3	119.3	129.2	139.2	149.1	159.0	169.0
45	9.97	19.94	29.90	39.9	49.8	59.8	69.8	79.8	89.7	109.7	119.6	129.6	139.6	149.5	159.5	169.5
46	10.00	19.99	29.99	40.0	50.0	60.0	70.0	80.0	90.0	110.0	120.0	130.0	140.0	150.0	160.0	169.9
47	10.02	20.05	30.08	40.1	50.1	60.2	70.2	80.2	90.2	110.3	120.3	130.3	140.4	150.4	160.4	170.4
48	10.05	20.11	30.16	40.2	50.3	60.3	70.4	80.4	90.5	110.6	120.6	130.7	140.8	150.8	160.9	170.9
49	10.08	20.16	30.25	40.3	50.4	60.5	70.6	80.7	90.8	110.9	121.0	131.1	141.2	151.2	161.3	171.4
50	10.11	20.22	30.33	40.4	50.6	60.7	70.8	80.9	91.0	111.2	121.3	131.4	141.6	151.7	161.8	171.9
51	10.14	20.28	30.42	40.6	50.7	60.8	71.0	81.1	91.3	111.5	121.7	131.8	142.0	152.1	162.2	172.4
52	10.17	20.34	30.50	40.7	50.8	61.0	71.2	81.3	91.5	111.9	122.0	132.2	142.4	152.5	162.7	172.9
53	10.20	20.40	30.59	40.8	51.0	61.2	71.4	81.6	91.8	112.2	122.4	132.6	142.8	152.9	163.1	173.3
54	10.22	20.45	30.68	40.9	51.1	61.4	71.6	81.8	92.0	112.5	122.7	132.9	143.2	153.4	163.6	173.8
55	10.25	20.51	30.76	41.0	51.3	61.5	71.8	82.0	92.3	112.8	123.0	133.3	143.6	153.8	164.1	174.3
56	10.28	20.57	30.84	41.1	51.4	61.7	72.0	82.2	92.5	113.1	123.4	133.6	143.9	154.2	164.5	174.8
57	10.31	20.63	30.93	41.2	51.6	61.9	72.2	82.5	92.8	113.4	123.7	134.0	144.3	154.6	165.0	175.3
58	10.34	20.58	31.02	41.4	51.7	62.0	72.4	82.7	93.0	113.7	124.1	134.4	144.8	155.1	165.4	175.8
59	10.37	20.74	31.10	41.5	51.8	62.2	72.6	82.9	93.3	114.0	124.4	134.8	145.1	155.5	165.9	176.2
Horz. Dist.	99.08	198.2	297.2	396.3	495.4	594	694	793	892	1090	1189	1288	1387	1486	1585	1684

5°

1800	1900	2100	2200	2300	2400	2500	2600	2700	2800	2900	3100	3200	3300	3400	3500	′
156.3	165.0	182.3	191.0	200.0	208.4	217.1	225.7	234.4	243.1	251.8	269.2	277.8	286.5	295.2	303.9	0
156.8	165.5	182.9	191.6	200.4	209.1	217.8	226.5	235.2	243.9	252.6	270.0	278.8	287.5	296.2	304.9	1
157.3	166.0	183.5	192.3	201.0	209.7	218.5	227.2	236.0	244.7	253.4	270.9	280.0	288.4	297.1	305.9	2
157.8	166.6	184.1	192.9	201.7	210.5	219.2	228.0	236.7	245.5	254.3	271.8	280.6	289.4	298.1	306.9	3
158.3	167.1	184.7	193.5	202.3	211.1	219.9	228.7	237.5	246.3	255.1	272.7	281.5	290.3	299.1	307.9	4
158.8	167.7	185.3	194.2	203.0	211.8	220.6	229.5	238.3	247.1	255.9	273.6	282.4	291.2	300.1	308.9	5
159.4	168.2	185.9	194.8	203.6	212.5	221.4	230.2	239.0	247.9	256.8	274.5	283.3	292.2	301.0	309.9	6
159.9	168.8	186.5	195.4	204.3	213.2	222.1	231.0	239.8	248.7	257.6	275.4	284.3	293.1	302.0	310.9	7
160.4	169.3	187.1	196.0	205.0	213.9	222.8	231.7	240.6	249.5	258.4	276.3	285.2	294.1	303.0	311.9	8
160.9	169.9	187.7	196.7	205.6	214.6	223.5	232.4	241.4	250.3	259.3	277.1	286.1	295.1	304.0	312.9	9
161.4	170.4	188.3	197.3	206.3	215.2	224.2	233.2	242.1	251.1	260.1	278.0	287.0	295.9	304.9	313.9	10
162.0	171.0	188.9	197.9	206.9	215.9	224.9	233.9	242.9	251.9	260.9	278.9	287.9	296.9	305.9	314.9	11
162.5	171.5	189.5	198.6	207.6	216.6	225.6	234.7	243.7	252.7	261.7	279.8	288.8	297.9	306.9	315.9	12
163.0	172.0	190.1	199.2	208.3	217.3	226.4	235.4	244.5	253.5	262.6	280.7	289.7	298.8	307.9	316.9	13
163.5	172.6	190.7	199.8	208.9	218.0	227.1	236.2	245.2	254.3	263.4	281.6	290.7	299.7	308.8	317.9	14
164.0	173.1	191.4	200.5	209.6	218.7	227.8	236.9	246.0	255.1	264.2	282.5	291.6	300.7	309.8	318.9	15
164.5	173.7	192.0	201.1	210.2	219.4	228.5	237.7	246.8	255.9	265.1	283.4	292.5	301.6	310.8	319.9	16
165.0	174.2	192.5	201.7	210.9	220.1	229.2	238.4	247.6	256.7	265.9	284.2	293.4	302.6	311.7	320.9	17
165.6	174.8	193.1	202.3	211.5	220.7	229.9	239.1	248.3	257.6	266.7	285.1	294.3	303.5	312.7	321.9	18
166.1	175.3	193.7	203.0	212.2	221.4	230.7	239.9	249.1	258.3	267.6	286.0	295.2	304.5	313.7	322.9	19
166.6	175.8	194.3	203.6	212.8	222.1	231.4	240.6	249.9	259.1	268.4	286.9	296.1	305.4	314.6	323.9	20
167.1	176.4	195.0	204.2	213.5	222.8	232.1	241.4	250.7	259.9	269.2	287.8	297.0	306.4	315.6	324.9	21
167.6	176.9	195.6	204.9	214.2	223.5	232.8	242.1	251.4	260.7	270.0	288.7	298.0	307.3	316.6	325.9	22
168.1	177.5	196.2	205.5	214.8	224.2	233.5	242.9	252.2	261.5	270.9	289.6	298.9	308.2	317.6	326.9	23
168.6	178.0	196.7	206.1	215.5	224.9	234.2	243.6	253.0	262.3	271.7	290.4	299.8	309.2	318.5	327.9	24
169.2	178.6	197.3	206.7	216.1	225.5	234.9	244.3	253.7	263.1	272.6	291.3	300.7	310.1	319.5	328.9	25
169.7	179.1	197.9	207.4	216.8	226.2	235.6	245.1	254.5	263.9	273.4	292.2	301.6	311.1	320.5	329.9	26
170.2	179.7	198.6	208.0	217.5	226.9	236.4	245.8	255.3	264.7	274.2	293.1	302.6	312.0	321.5	330.9	27
170.7	180.2	199.2	208.6	218.1	227.6	237.1	246.6	256.1	265.5	275.0	294.0	303.5	313.0	322.4	331.9	28
171.2	180.7	199.7	209.3	218.8	228.3	237.8	247.3	256.8	266.3	275.8	294.9	304.4	313.9	323.4	332.9	29
171.7	181.3	200.3	209.9	219.4	229.0	238.5	248.0	257.6	267.1	276.7	295.8	305.3	314.8	324.4	333.9	30
172.2	181.8	200.9	210.5	220.1	229.7	239.2	248.8	258.4	267.9	277.5	296.6	306.2	315.8	325.4	334.9	31
172.8	182.4	201.5	211.1	220.7	230.3	239.9	249.5	259.1	268.7	278.3	297.5	307.1	316.7	326.3	335.9	32
173.3	182.9	202.1	211.8	221.4	231.0	240.6	250.3	259.9	269.5	279.2	298.4	308.0	317.7	327.3	336.9	33
173.8	183.4	202.7	212.4	222.1	231.7	241.4	251.0	260.7	270.3	280.0	299.3	308.9	318.6	328.3	337.9	34
174.3	184.0	203.3	213.0	222.7	232.4	242.1	251.8	261.4	271.1	280.8	300.2	309.9	319.6	329.2	338.9	35
174.8	184.5	203.9	213.7	223.4	233.1	242.8	252.5	262.2	271.9	281.6	301.1	310.8	320.5	330.2	339.9	36
175.3	185.1	204.5	214.3	224.0	233.8	243.5	253.3	263.0	272.7	282.5	302.0	311.7	321.4	331.2	340.9	37
175.8	185.6	205.1	214.9	224.7	234.5	244.2	254.0	263.8	273.5	283.3	302.8	312.6	322.4	332.1	341.9	38
176.4	186.2	205.7	215.5	225.3	235.1	244.9	254.7	264.5	274.3	284.1	303.7	313.5	323.3	333.1	342.9	39
176.9	186.7	206.3	216.2	226.0	235.8	245.6	255.5	265.3	275.1	285.0	304.6	314.4	324.3	334.1	343.9	40
177.4	187.2	206.9	216.8	226.7	236.5	246.4	256.2	266.0	275.9	285.8	305.5	315.3	325.2	335.1	344.9	41
177.9	187.8	207.5	217.4	227.3	237.2	247.1	257.0	266.8	276.7	286.6	306.4	316.2	326.1	336.0	345.9	42
178.4	188.3	208.1	218.0	227.9	237.9	247.8	257.7	267.6	277.5	287.4	307.3	317.2	327.1	337.0	346.9	43
178.9	188.9	208.7	218.7	228.6	238.6	248.5	258.4	268.4	278.3	288.3	308.1	318.1	328.0	338.0	347.9	44
179.4	189.4	209.3	219.3	229.3	239.2	249.2	259.2	269.1	279.1	289.1	309.0	319.0	329.0	338.9	348.9	45
179.9	189.9	209.9	219.9	229.9	239.9	249.9	259.9	269.9	279.9	289.9	309.9	319.9	329.9	339.9	349.9	46
180.5	190.5	210.5	220.6	230.6	240.6	250.6	260.7	270.7	280.7	290.7	310.8	320.8	330.9	340.9	350.9	47
181.0	191.0	211.2	221.2	231.2	241.3	251.4	261.4	271.5	281.5	291.6	311.7	321.7	331.8	341.8	351.9	48
181.5	191.6	211.7	221.8	231.9	242.0	252.1	262.1	272.2	282.3	292.4	312.6	322.6	332.7	342.8	352.9	49
182.0	192.0	212.4	222.4	232.6	242.7	252.8	262.9	273.0	283.1	293.2	313.4	323.6	333.7	343.8	353.9	50
182.5	192.7	212.9	223.1	233.2	243.3	253.5	263.6	273.8	283.9	294.0	314.3	324.5	334.6	344.8	354.9	51
183.0	193.2	213.5	223.7	233.9	244.0	254.2	264.4	274.5	284.7	294.9	315.2	325.4	335.5	345.7	355.9	52
183.5	193.7	214.1	224.3	234.5	244.7	254.9	265.1	275.3	285.5	295.7	316.1	326.3	336.5	346.7	356.9	53
184.0	194.3	214.7	225.0	235.2	245.4	255.6	265.8	276.1	286.3	296.5	317.0	327.2	337.4	347.6	357.9	54
184.6	194.8	215.3	225.6	235.8	246.1	256.3	266.6	276.8	287.1	297.4	317.9	328.1	338.4	348.6	358.9	55
185.1	195.4	215.9	226.2	236.5	246.8	257.0	267.3	277.6	287.9	298.2	318.7	329.0	339.3	349.6	359.8	56
185.6	195.9	216.5	226.8	237.1	247.4	257.8	268.1	278.4	288.7	299.0	319.6	329.9	340.2	350.5	360.8	57
186.1	196.4	217.1	227.4	237.8	248.1	258.5	268.8	279.1	289.5	299.8	320.5	330.8	341.2	351.5	361.8	58
186.6	197.0	217.7	228.1	238.4	248.8	259.2	269.5	279.9	290.3	300.7	321.4	331.7	342.1	352.5	362.8	59
1783	1882	2081	2180	2279	2378	2477	2576	2675	2774	2873	3071	3170	3270	3369	3468	Horz. Dist.

TABLE III.—(*Continued*)

6°

′	100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	1700
0	10.40	20.79	31.19	41.6	52.0	62.4	72.8	83.2	93.6	114.4	124.7	135.1	145.5	155.9	166.3	176.7
1	10.42	20.85	31.27	41.7	52.1	62.5	73.0	83.4	93.8	114.7	125.1	135.5	145.9	156.4	166.8	177.2
2	10.45	20.90	31.36	41.8	52.3	62.7	73.2	83.6	94.1	115.0	125.4	135.9	146.3	156.8	167.2	177.7
3	10.48	20.96	31.44	41.9	52.4	62.9	73.4	83.8	94.3	115.3	125.8	136.2	146.7	157.2	167.7	178.2
4	10.51	21.02	31.53	42.0	52.5	63.1	73.6	84.1	94.6	115.6	126.1	136.6	147.1	157.6	168.2	178.8
5	10.54	21.08	31.61	42.2	52.7	63.2	73.8	84.3	94.8	115.9	126.5	137.0	147.5	158.1	168.6	179.1
6	10.57	21.13	31.69	42.3	52.8	63.4	74.0	84.5	95.1	116.2	126.8	137.4	147.9	158.5	169.1	179.6
7	10.59	21.19	31.78	42.4	53.0	63.6	74.2	84.8	95.4	116.5	127.1	137.7	148.3	158.9	169.5	180.1
8	10.62	21.25	31.87	42.5	53.1	63.7	74.4	85.0	95.6	116.8	127.5	138.1	148.7	159.3	170.0	180.6
9	10.65	21.30	31.95	42.6	53.3	63.9	74.6	85.2	95.9	117.2	127.8	138.5	149.1	159.8	170.4	181.1
10	10.68	21.36	32.04	42.7	53.4	64.1	74.8	85.4	96.1	117.5	128.2	138.8	149.5	160.2	170.9	181.6
11	10.71	21.42	32.12	42.8	53.5	64.3	75.0	85.7	96.4	117.8	128.5	139.2	149.9	160.6	171.3	182.0
12	10.74	21.47	32.21	42.9	53.7	64.4	75.2	85.9	96.6	118.1	128.8	139.6	150.3	161.1	171.8	182.5
13	10.76	21.53	32.30	43.1	53.8	64.6	75.4	86.1	96.9	118.4	129.2	139.9	150.7	161.5	172.2	183.0
14	10.79	21.59	32.38	43.2	54.0	64.8	75.6	86.3	97.1	118.7	129.5	140.3	151.1	161.9	172.7	183.5
15	10.82	21.64	32.47	43.3	54.1	64.9	75.8	86.6	97.4	119.0	129.9	140.7	151.5	162.3	173.2	184.0
16	10.85	21.70	32.55	43.4	54.2	65.1	76.0	86.8	97.6	119.4	130.2	141.1	151.9	162.8	173.6	184.5
17	10.88	21.76	32.64	43.5	54.4	65.3	76.2	87.0	97.9	119.7	130.5	141.4	152.3	163.2	174.1	184.9
18	10.91	21.81	32.72	43.6	54.5	65.4	76.3	87.3	98.2	120.0	130.9	141.8	152.7	163.6	174.5	185.4
19	10.94	21.87	32.81	43.7	54.7	65.6	76.5	87.5	98.4	120.3	131.2	142.2	153.1	164.0	175.0	185.9
20	10.96	21.93	32.89	43.9	54.8	65.8	76.7	87.7	98.7	120.6	131.6	142.5	153.5	164.5	175.4	186.4
21	10.99	21.98	32.98	44.0	55.0	66.0	76.9	87.9	98.9	120.9	131.9	142.9	153.9	164.9	175.9	186.9
22	11.02	22.04	33.06	44.1	55.1	66.1	77.1	88.2	99.2	121.2	132.2	143.3	154.3	165.3	176.3	187.3
23	11.05	22.10	33.15	44.2	55.2	66.3	77.3	88.4	99.4	121.5	132.6	143.6	154.7	165.7	176.8	187.8
24	11.08	22.16	33.23	44.3	55.4	66.5	77.5	88.6	99.7	121.8	132.9	144.0	155.1	166.2	177.2	188.3
25	11.11	22.21	33.32	44.4	55.5	66.6	77.7	88.8	99.9	122.2	133.3	144.4	155.5	166.6	177.7	188.8
26	11.13	22.27	33.40	44.5	55.7	66.8	77.9	89.1	100.2	122.5	133.6	144.7	155.9	167.0	178.1	189.3
27	11.16	22.33	33.49	44.6	55.8	67.0	78.1	89.3	100.5	122.8	134.0	145.1	156.3	167.4	178.6	189.8
28	11.19	22.38	33.57	44.8	56.0	67.1	78.3	89.5	100.7	123.1	134.3	145.5	156.7	167.9	179.0	190.2
29	11.22	22.44	33.66	44.9	56.1	67.3	78.5	89.7	101.0	123.4	134.6	145.8	157.1	168.3	179.5	190.7
30	11.25	22.49	33.74	45.0	56.2	67.5	78.7	90.0	101.2	123.7	135.0	146.2	157.5	168.7	180.0	191.2
31	11.28	22.55	33.83	45.1	56.4	67.7	78.9	90.2	101.5	124.0	135.3	146.6	157.9	169.1	180.4	191.7
32	11.30	22.61	33.91	45.2	56.5	67.8	79.1	90.4	101.7	124.3	135.6	147.0	158.3	169.6	180.9	192.2
33	11.32	22.66	34.00	45.3	56.7	68.0	79.3	90.7	102.0	124.7	136.0	147.3	158.7	170.0	181.3	192.6
34	11.36	22.72	34.08	45.4	56.8	68.2	79.5	90.9	102.2	125.0	136.3	147.7	159.0	170.4	181.8	193.1
35	11.39	22.78	34.17	45.6	56.9	68.3	79.7	91.1	102.5	125.3	136.7	148.1	159.4	170.8	182.2	193.6
36	11.42	22.84	34.25	45.7	57.1	68.5	79.9	91.3	102.8	125.6	137.0	148.4	159.8	171.3	182.7	194.1
37	11.45	22.89	34.34	45.8	57.2	68.7	80.1	91.6	103.0	125.9	137.4	148.8	160.2	171.7	183.1	194.6
38	11.47	22.95	34.42	45.9	57.4	68.8	80.3	91.8	103.3	126.2	137.7	149.2	160.6	172.1	183.6	195.1
39	11.50	23.00	34.51	46.0	57.5	69.0	80.5	92.0	103.5	126.5	138.0	149.5	161.0	172.5	184.0	195.5
40	11.53	23.06	34.59	46.1	57.6	69.2	80.7	92.2	103.8	126.8	138.4	149.9	161.4	173.0	184.5	196.0
41	11.56	23.12	34.68	46.2	57.8	69.4	80.9	92.5	104.0	127.1	138.7	150.3	161.8	173.4	184.9	196.5
42	11.59	23.18	34.76	46.4	57.9	69.5	81.1	92.7	104.3	127.5	139.0	150.6	162.2	173.8	185.4	197.0
43	11.62	23.23	34.84	46.5	58.1	69.7	81.3	92.9	104.5	127.8	139.4	151.0	162.6	174.2	185.8	197.5
44	11.64	23.29	34.93	46.6	58.2	60.9	81.5	93.2	104.8	128.1	139.7	151.4	163.0	174.7	186.3	197.9
45	11.67	23.34	35.02	46.7	58.4	70.0	81.7	93.4	105.0	128.4	140.1	151.7	163.4	175.1	186.8	198.4
46	11.70	23.40	35.10	46.8	58.5	70.2	81.9	93.6	105.3	128.7	140.4	152.1	163.8	175.5	187.2	198.9
47	11.73	23.46	35.19	46.9	58.6	70.4	82.1	93.8	105.6	129.0	140.7	152.5	164.2	175.9	187.7	199.4
48	11.76	23.51	35.27	47.0	58.8	70.5	82.3	94.1	105.8	129.3	141.1	152.8	164.6	176.4	188.1	199.9
49	11.79	23.57	35.36	47.1	58.9	70.7	82.5	94.3	106.1	129.6	141.4	153.2	165.0	176.8	188.6	200.3
50	11.81	23.63	35.44	47.3	59.1	70.9	82.7	94.5	106.3	129.9	141.8	153.6	165.4	177.2	189.0	200.8
51	11.84	23.68	35.53	47.4	59.2	71.0	82.9	94.7	106.6	130.3	142.1	153.9	165.8	177.6	189.5	201.2
52	11.87	23.74	35.61	47.5	59.4	71.2	83.1	95.0	106.8	130.6	142.4	154.3	166.2	178.0	189.9	201.8
53	11.90	23.80	35.70	47.6	59.5	71.4	83.3	95.2	107.1	130.9	142.8	154.7	166.6	178.5	190.4	202.3
54	11.93	23.85	35.78	47.7	59.6	71.6	83.5	95.4	107.3	131.2	143.1	155.0	167.0	178.9	190.8	202.8
55	11.96	23.91	35.86	47.8	59.8	71.7	83.7	95.6	107.6	131.5	143.5	155.4	167.4	179.3	191.3	203.2
56	11.98	23.97	35.95	47.9	59.9	71.9	83.9	95.9	107.8	131.8	143.8	155.8	167.8	179.7	191.7	203.7
57	12.01	24.02	36.03	48.0	60.1	72.1	84.1	96.1	108.1	132.1	144.1	156.1	168.2	180.2	192.2	204.2
58	12.04	24.08	36.12	48.2	60.2	72.2	84.3	96.3	108.4	132.4	144.5	156.5	168.6	180.6	192.6	204.7
59	12.07	24.14	36.20	48.3	60.3	72.4	84.5	96.5	108.7	132.7	144.8	156.9	169.0	181.0	193.1	205.2
Horz. Dist.	98.72	197.4	296.2	394.9	493.6	592	691	790	888	1086	1185	1283	1382	1418	1579	1678

TABLE III.—(*Continued*)

7°

100	200	300	400	500	600	700	800	900	1100	1200	1300	1400	1500	1600	′
12.10	24.19	36.29	48.4	60.5	72.6	84.7	96.8	108.9	133.1	145.2	157.2	169.4	181.4	193.5	0
12.12	24.25	36.37	48.5	60.6	72.7	84.9	97.0	109.1	133.4	145.5	157.6	169.7	181.9	194.0	1
12.15	24.30	36.46	48.6	60.8	72.9	85.1	97.2	109.4	133.7	145.8	158.0	170.1	182.3	194.4	2
12.18	24.36	36.54	48.7	60.9	73.1	85.3	97.4	109.6	134.0	146.2	158.4	170.5	182.7	194.9	3
12.21	24.42	36.63	48.8	61.1	73.2	85.5	97.7	109.9	134.3	146.5	158.7	170.9	183.1	195.3	4
12.24	24.47	36.71	48.9	61.2	73.4	85.7	97.9	110.1	134.6	146.8	159.1	171.3	183.6	195.8	5
12.27	24.53	36.80	49.1	61.3	73.6	85.9	98.1	110.4	134.9	147.2	159.4	171.7	184.0	196.2	6
12.29	24.59	36.88	49.2	61.5	73.8	86.0	98.3	110.6	135.2	147.5	159.8	172.1	184.4	19.67	7
12.32	24.64	36.97	49.3	61.6	73.9	86.2	98.6	110.9	135.5	147.9	160.2	172.5	184.8	197.2	8
12.35	24.70	37.05	49.4	61.8	74.1	86.4	98.8	111.2	135.8	148.2	160.6	172.9	185.2	197.6	9
12.38	24.76	37.13	49.5	61.9	74.3	86.6	99.0	111.4	136.2	148.6	160.9	173.3	185.7	198.0	10
12.41	24.81	37.22	49.6	62.0	74.4	86.8	99.2	111.7	136.5	148.9	161.3	173.7	186.1	198.5	11
12.43	24.87	37.30	49.7	62.2	74.6	87.0	99.5	111.9	136.8	149.2	161.6	174.1	186.5	198.8	12
12.46	24.92	37.39	49.8	62.3	74.8	87.2	99.7	112.2	137.1	149.6	162.0	174.5	186.9	199.4	13
12.49	24.98	37.47	50.0	62.5	74.9	87.4	99.9	112.4	137.4	149.9	162.4	174.9	187.4	199.9	14
12.52	25.04	37.56	50.1	62.6	75.1	87.6	100.2	112.7	137.7	150.2	162.7	175.3	187.8	200.3	15
12.55	25.09	37.64	50.2	62.7	75.3	87.8	100.4	112.9	138.0	150.6	163.1	175.7	188.2	200.7	16
12.58	25.15	37.73	50.3	62.9	75.4	88.0	100.6	113.2	138.3	150.9	163.5	176.1	188.6	201.2	17
12.60	25.21	37.81	50.4	63.0	75.6	88.2	100.8	113.4	138.6	151.2	163.8	176.4	189.0	201.7	18
12.63	25.26	37.89	50.5	63.2	75.8	88.4	101.0	113.7	138.9	151.6	164.2	176.8	189.5	202.1	19
12.66	25.32	37.98	50.6	63.3	76.0	88.6	101.3	113.9	139.3	151.9	164.6	177.2	189.9	202.6	20
12.69	25.38	38.06	50.8	63.4	76.1	88.8	101.5	114.2	139.6	152.3	164.9	177.6	190.3	203.0	21
12.72	25.43	38.15	50.9	63.6	76.3	89.0	101.7	114.4	139.9	152.6	165.3	178.0	190.7	203.5	22
12.74	25.49	38.23	51.0	63.7	76.5	89.2	102.0	114.7	140.2	152.9	165.7	178.4	191.2	203.9	23
12.77	25.54	38.32	51.1	63.9	76.6	89.4	102.2	115.0	140.5	153.3	166.0	178.8	191.6	204.4	24
12.80	25.60	38.40	51.2	64.0	76.8	89.6	102.4	115.2	140.8	153.6	166.4	179.2	192.0	204.8	25
12.83	25.66	38.49	51.3	64.1	77.0	89.8	102.6	115.5	141.1	153.9	166.8	179.6	192.4	205.3	26
12.86	25.71	38.57	51.4	64.3	77.1	90.0	102.8	115.7	141.4	154.3	167.1	180.0	192.8	205.7	27
12.88	25.77	38.65	51.5	64.4	77.3	90.2	103.1	116.0	141.7	154.6	167.4	180.4	193.3	206.2	28
12.91	25.83	38.74	51.6	64.6	77.5	90.4	103.3	116.2	142.0	155.0	167.9	180.8	193.7	206.6	29
12.94	25.88	38.82	51.8	64.7	77.6	90.6	103.5	116.5	142.4	155.3	168.2	181.2	194.1	207.0	30
12.97	25.94	38.91	51.9	64.8	77.8	90.8	103.8	116.7	142.7	155.6	168.6	181.6	194.5	207.5	31
13.00	25.99	38.99	52.0	65.0	78.0	91.0	104.0	117.0	143.0	156.0	169.0	182.0	195.0	208.0	32
13.02	26.05	39.08	52.1	65.1	78.1	91.2	104.2	117.2	143.3	156.3	169.3	182.4	195.4	208.4	33
13.05	26.11	39.16	52.2	65.3	78.3	91.4	104.4	117.5	143.6	156.6	169.7	182.7	195.8	208.9	34
13.08	26.16	39.24	52.3	65.4	78.5	91.6	104.6	117.7	143.9	157.0	170.0	183.1	196.2	209.3	35
13.11	26.22	39.33	52.4	65.5	78.7	91.8	104.9	118.0	144.2	157.3	170.4	183.5	196.6	209.8	36
13.14	26.28	39.41	52.6	65.7	78.8	92.0	105.1	118.2	144.5	157.6	170.8	183.9	197.1	210.2	37
13.17	26.33	39.50	52.7	65.8	79.0	92.2	105.3	118.5	144.8	158.0	171.2	184.2	197.5	210.6	38
13.20	26.40	39.60	52.8	66.0	79.2	92.4	105.6	118.8	145.2	158.4	171.6	184.8	198.0	211.2	39
13.22	26.44	39.66	52.9	66.1	79.3	92.6	105.8	119.0	145.4	158.7	171.9	185.1	198.3	211.5	40
13.25	26.50	39.75	53.0	66.2	79.5	92.8	106.0	119.2	145.8	159.0	172.2	185.5	198.8	212.0	41
13.28	26.56	39.83	53.1	66.4	79.7	92.9	106.2	119.5	146.1	159.3	172.6	185.9	199.2	212.4	42
13.31	26.61	39.92	53.2	66.5	79.8	93.1	106.4	119.8	146.4	159.7	173.0	186.3	199.6	212.9	43
13.33	26.67	40.00	53.3	66.7	80.0	93.3	106.7	120.0	146.7	160.0	173.3	186.7	200.0	213.3	44
13.36	26.72	40.09	53.4	66.8	80.2	93.5	106.9	120.3	147.0	160.3	173.7	187.1	200.4	213.8	45
13.39	26.78	40.17	53.6	67.0	80.3	93.7	107.1	120.5	147.2	160.6	174.0	187.4	200.7	214.1	46
13.42	26.84	40.25	53.7	67.1	80.5	93.9	107.3	120.8	147.6	161.0	174.4	187.8	201.3	214.7	47
13.45	26.89	40.34	53.8	67.2	80.7	94.1	107.6	121.0	147.9	161.4	174.8	188.2	201.7	215.1	48
13.47	26.94	40.42	53.9	67.4	80.8	94.3	107.8	121.3	148.2	161.7	175.2	188.6	202.1	215.6	49
13.50	27.00	40.50	54.0	67.5	81.0	94.5	108.0	121.5	148.6	162.0	175.5	189.0	202.5	216.0	50
13.53	27.06	40.59	54.1	67.7	81.2	94.7	108.2	121.8	148.8	162.4	175.9	189.4	203.0	216.5	51
13.56	27.12	40.67	54.2	67.8	81.3	94.9	108.5	122.0	149.1	162.7	176.2	189.8	203.4	216.9	52
13.59	27.17	40.76	54.3	67.9	81.5	95.1	108.7	122.3	149.4	163.0	176.6	190.2	203.8	217.4	53
13.61	27.23	40.84	54.5	68.1	81.7	95.3	108.9	122.5	149.8	163.4	177.0	190.6	204.2	217.8	54
13.64	27.28	40.93	54.6	68.2	81.8	95.5	109.1	122.8	150.1	163.7	177.3	191.0	204.6	218.3	55
13.67	27.34	41.01	54.7	68.4	82.0	95.7	109.4	123.0	150.4	164.0	177.7	191.4	205.0	218.7	56
13.70	27.40	41.09	54.8	68.5	82.2	95.9	109.6	123.3	150.7	164.4	178.1	191.8	205.5	219.2	57
13.73	27.45	41.18	54.9	68.6	82.4	96.1	109.8	123.5	151.0	164.7	178.4	192.2	205.9	219.6	58
13.75	27.51	41.26	55.0	68.8	82.5	96.3	110.0	123.8	151.3	165.0	178.8	192.6	206.3	220.1	59
98.29	196.6	294.9	393.2	491.4	590	688	786	885	1081	1179	1278	1376	1474	1573	Horz. Dist.

TABLE III.—(*Continued*)

8°

′	100	200	300	400	500	600	700	800	900	1100
0	13.78	27.56	41.35	55.1	68.9	82.7	96.5	110.3	124.0	151.6
1	13.81	27.62	41.43	55.2	69.0	82.9	96.7	110.5	124.3	151.9
2	13.84	27.68	41.51	55.4	69.2	83.0	96.9	110.7	124.5	152.2
3	13.87	27.73	41.60	55.5	69.3	83.2	97.1	110.9	124.8	152.5
4	13.89	27.78	41.68	55.6	69.5	83.4	97.3	111.2	125.0	152.8
5	13.92	27.84	41.76	55.7	69.6	83.5	97.4	111.4	125.3	153.1
6	13.95	27.90	41.85	55.8	69.8	83.7	97.6	111.6	125.6	153.4
7	13.98	27.96	41.93	55.9	69.9	83.9	97.8	111.8	125.8	153.8
8	14.01	28.01	42.02	56.0	70.0	84.0	98.0	112.0	126.0	154.1
9	14.03	28.07	42.10	56.1	70.2	84.2	98.2	112.3	126.3	154.4
10	14.06	28.12	42.18	56.2	70.3	84.4	98.4	112.5	126.6	154.7
11	14.09	28.18	42.27	56.4	70.4	84.5	98.6	112.7	126.8	155.0
12	14.12	28.23	42.35	56.5	70.6	84.7	98.8	112.9	127.0	155.3
13	14.14	28.29	42.44	56.6	70.7	84.9	99.0	113.2	127.3	155.6
14	14.17	28.35	42.52	56.7	70.9	85.0	99.2	113.4	127.6	155.9
15	14.20	28.40	42.60	56.8	71.0	85.2	99.4	113.6	127.8	156.2
16	14.23	28.46	42.68	56.9	71.1	85.4	99.6	113.8	128.0	156.5
17	14.26	28.51	42.77	57.0	71.3	85.5	99.8	114.0	128.3	156.8
18	14.28	28.57	42.85	57.1	71.4	85.7	100.0	114.3	128.6	157.1
19	14.31	28.62	42.94	57.2	71.6	85.9	100.2	114.5	128.8	157.4
20	14.34	28.68	43.02	57.4	71.7	86.0	100.4	114.7	129.1	157.7
21	14.37	28.74	43.10	57.5	71.8	86.2	100.6	114.9	129.3	158.0
22	14.40	28.79	43.19	57.6	72.0	86.4	100.8	115.2	129.6	158.4
23	14.42	28.95	43.27	57.7	72.1	86.5	101.0	115.4	129.8	158.7
24	14.45	28.90	43.36	57.8	72.3	86.7	101.2	115.6	130.1	159.0
25	14.48	29.96	43.44	57.9	72.4	86.9	101.4	115.8	130.3	159.3
26	14.51	29.02	43.52	58.0	72.5	87.0	101.6	116.1	130.6	159.6
27	14.54	29.07	43.60	58.1	72.7	87.2	101.7	116.3	130.8	159.9
28	14.56	29.13	43.69	58.2	72.8	87.4	101.9	116.5	131.1	160.2
29	14.59	29.18	43.77	58.4	73.0	87.6	102.1	116.7	131.3	160.5
30	14.62	29.24	43.85	58.5	73.1	87.7	102.3	116.9	131.6	160.8
31	14.65	29.29	43.94	58.6	73.2	87.9	102.5	117.2	131.8	161.1
32	14.67	29.35	44.02	58.7	73.4	88.0	102.7	117.4	132.1	161.4
33	14.70	29.40	44.11	58.8	73.5	88.2	102.9	117.6	132.3	161.7
34	14.73	29.46	44.19	58.9	73.6	88.4	103.1	117.8	132.6	162.0
35	14.76	29.52	44.27	59.0	73.8	88.6	103.3	118.1	132.8	162.3
36	14.79	29.57	44.36	59.1	73.9	88.7	103.5	118.3	133.1	162.6
37	14.81	29.63	44.44	59.2	74.1	88.9	103.7	118.5	133.3	162.9
38	14.84	29.68	44.52	59.4	74.2	89.0	103.9	118.7	133.6	163.2
39	14.87	29.74	44.61	59.5	74.3	89.2	104.1	119.0	133.8	163.6
40	14.90	29.78	44.69	59.6	74.5	89.4	104.3	119.2	134.1	163.9
41	14.92	29.85	44.77	59.7	74.6	89.6	104.5	119.4	134.3	164.2
42	14.95	29.90	44.86	59.8	74.8	89.7	104.7	119.6	134.6	164.5
43	14.98	29.96	44.94	59.9	74.9	89.9	104.9	119.8	134.8	164.8
44	15.01	30.02	45.02	60.0	75.0	90.0	105.0	120.1	135.1	165.1
45	15.04	30.07	45.11	60.1	75.2	90.2	105.2	120.3	135.3	165.4
46	15.06	30.13	45.18	60.2	75.3	90.4	105.4	120.5	135.6	165.7
47	15.09	30.18	45.27	60.4	75.5	90.6	105.6	120.7	135.8	166.0
48	15.12	30.24	45.36	60.5	75.6	90.7	105.8	121.0	136.1	166.3
49	15.15	30.29	45.44	60.6	75.7	90.9	106.0	121.2	136.3	166.6
50	15.17	30.35	45.52	60.7	75.9	91.0	106.2	121.4	136.6	166.9
51	15.20	30.40	45.60	60.8	76.0	91.2	106.4	121.6	136.8	167.2
52	15.23	30.46	45.69	60.9	76.2	91.4	106.6	121.8	137.1	167.5
53	15.26	30.51	45.77	61.0	76.3	91.5	106.8	122.1	137.3	167.8
54	15.28	30.57	45.86	61.1	76.4	91.7	107.0	122.3	137.6	168.1
55	15.31	30.62	45.94	61.2	76.6	91.9	107.2	122.5	137.8	168.4
56	15.34	30.68	46.02	61.4	76.7	92.0	107.4	122.7	138.1	168.7
57	15.37	30.74	46.10	61.5	76.8	92.2	107.6	122.9	138.3	169.0
58	15.40	30.79	46.19	61.6	77.0	92.4	107.8	123.2	138.6	169.4
59	15.42	30.85	46.27	61.7	77.1	92.5	108.0	123.4	138.8	169.6
Horz. Dist.	97.82	195.6	293.5	391.3	489.1	587	685	783	880	1076

9°

	100	200	300	400	500	600	700	800	900	1100
	15.45	30.90	46.35	61.8	77.3	92.7	108.2	123.6	139.1	170.0
	15.48	30.96	46.44	61.9	77.4	92.9	108.4	123.8	139.3	170.3
	15.51	31.01	46.52	62.0	77.5	93.0	108.5	124.0	139.6	170.6
	15.53	31.07	46.60	62.1	77.7	93.2	108.7	124.3	139.8	170.9
	15.56	31.12	46.68	62.2	77.8	93.4	108.9	124.5	140.0	171.2
	15.59	31.18	46.77	62.4	77.9	93.5	109.1	124.7	140.3	171.5
	15.62	31.23	46.85	62.5	78.1	93.7	109.3	124.9	140.6	171.8
	15.64	31.29	46.93	62.6	78.2	93.9	109.5	125.2	140.8	172.1
	15.67	31.34	47.02	62.7	78.4	94.0	109.7	125.4	141.0	172.4
	15.70	31.40	47.10	62.8	78.5	94.2	109.9	125.6	141.3	172.7
	15.73	31.45	47.18	62.9	78.6	94.4	110.1	125.8	141.5	173.0
	15.76	31.51	47.26	63.0	78.8	94.5	110.3	126.0	141.8	173.3
	15.78	31.56	47.35	63.1	78.9	94.7	110.5	126.3	142.0	173.6
	15.81	31.62	47.43	63.2	79.0	94.9	110.7	126.5	142.3	173.9
	15.84	31.68	47.51	63.4	79.2	95.0	110.9	126.7	142.5	174.2
	15.86	31.73	47.60	63.5	79.3	95.2	111.1	126.9	142.8	174.5
	15.89	31.79	47.68	63.6	79.5	95.4	111.2	127.1	143.0	174.8
	15.92	31.84	47.76	63.7	79.6	95.5	111.4	127.4	143.3	175.1
	15.95	31.90	47.84	63.8	79.7	95.7	111.6	127.6	143.5	175.4
	15.98	31.95	47.93	63.9	79.9	95.8	111.8	127.8	143.8	175.7
	16.00	32.01	48.01	64.0	80.0	96.0	112.0	128.0	144.0	176.0
	16.03	32.06	48.09	64.1	80.2	96.2	112.2	128.2	144.3	176.3
	16.06	32.12	48.17	64.2	80.3	96.4	112.4	128.5	144.5	176.6
	16.09	32.17	48.26	64.3	80.4	96.5	112.6	128.7	144.8	176.9
	16.11	32.23	48.34	64.4	80.6	96.7	112.8	128.9	145.0	177.2
	16.14	32.28	48.42	64.6	80.7	96.8	113.0	129.1	145.3	177.6
	16.17	32.34	48.51	64.7	80.8	97.0	113.2	129.4	145.5	177.8
	16.20	32.39	48.59	64.8	81.0	97.2	113.4	129.6	145.8	178.2
	16.22	32.45	48.67	64.9	81.1	97.3	113.6	129.8	146.0	178.5
	16.25	32.50	48.75	65.0	81.3	97.5	113.8	130.0	146.3	178.8
	16.28	32.56	48.84	65.1	81.4	97.7	114.0	130.2	146.5	179.1
	16.31	32.61	48.92	65.2	81.5	97.8	114.1	130.4	146.8	179.4
	16.33	32.67	49.00	65.3	81.7	98.0	114.3	130.7	147.0	179.7
	16.36	32.72	49.08	65.4	81.8	98.2	114.5	130.9	147.2	180.0
	16.39	32.78	49.17	65.6	81.9	98.3	114.7	131.1	147.5	180.3
	16.42	32.83	49.25	65.7	82.1	98.5	114.9	131.3	147.7	180.6
	16.44	32.89	49.33	65.8	82.2	98.7	115.1	131.6	148.0	180.9
	16.47	32.94	49.41	65.9	82.4	98.8	115.3	131.8	148.2	181.2
	16.50	33.00	49.50	66.0	82.5	99.0	115.5	132.0	148.5	181.5
	16.53	33.05	49.58	66.1	82.6	99.2	115.7	132.2	148.7	181.8
	16.55	33.11	49.66	66.2	82.8	99.3	115.9	132.4	149.0	182.1
	16.58	33.16	49.74	66.3	82.9	99.5	116.1	132.6	149.2	182.4
	16.61	33.22	49.82	66.4	83.0	99.6	116.3	132.9	149.5	182.7
	16.64	33.27	49.91	66.5	83.2	99.8	116.4	133.1	149.7	183.0
	16.66	33.33	50.00	66.6	83.3	100.0	116.6	133.3	150.0	183.3
	16.69	33.38	50.07	66.8	83.4	100.1	116.8	133.5	150.2	183.6
	16.72	33.44	50.15	66.9	83.6	100.3	117.0	133.7	150.5	183.9
	16.74	33.49	50.24	67.0	83.7	100.5	117.2	134.0	150.7	184.2
	16.77	33.54	50.32	67.1	83.9	100.6	117.4	134.2	151.0	184.5
	16.80	33.60	50.40	67.2	84.0	100.8	117.6	134.4	151.2	184.8
	16.83	33.66	50.48	67.3	84.1	101.0	117.8	134.6	151.4	185.1
	16.86	33.71	50.56	67.4	84.3	101.1	118.0	134.8	151.7	185.4
	16.88	33.76	50.65	67.5	84.4	101.3	118.2	135.1	151.9	185.7
	16.91	33.82	50.73	67.6	84.6	101.5	118.4	135.3	152.2	186.0
	16.94	33.87	50.81	67.8	84.7	101.6	118.6	135.5	152.4	186.3
	16.96	33.93	50.89	67.9	84.8	101.8	118.8	135.7	152.7	186.6
	16.99	33.98	50.98	68.0	85.0	102.0	118.9	135.9	152.9	186.9
	17.02	34.04	51.06	68.1	85.1	102.1	119.1	136.2	153.2	187.2
	17.05	34.09	51.14	68.2	85.2	102.3	119.3	136.4	153.4	187.5
	17.08	34.16	51.24	68.3	85.4	102.5	119.5	136.6	153.7	187.9
:.	97.28	194.6	291.9	389.2	486.4	584	681	778	876	1070

TABLE III.—(*Continued*)

10°

′	100	200	300	400	500	600	700	800	900	1100
0	17.10	34.20	51.30	68.4	85.5	102.6	119.7	136.8	153.9	188.1
1	17.13	34.26	51.39	68.5	85.6	102.8	119.9	137.0	154.2	188.4
2	17.16	34.31	51.47	68.6	85.8	102.9	120.1	137.2	154.4	188.7
3	17.18	34.37	51.55	68.7	85.9	103.1	120.3	137.5	154.6	189.0
4	17.21	34.42	51.63	68.8	86.0	103.3	120.5	137.7	154.9	189.3
5	17.24	34.48	51.71	69.0	86.2	103.4	120.7	137.9	155.1	189.6
6	17.26	34.53	51.80	69.1	86.3	103.6	120.9	138.1	155.4	189.9
7	17.29	34.58	51.88	69.2	86.5	103.8	121.0	138.3	155.6	190.2
8	17.32	34.64	51.96	69.3	86.6	103.9	121.2	138.6	155.9	190.5
9	17.35	34.69	52.04	69.4	86.7	104.1	121.4	138.8	156.1	190.8
10	17.37	34.75	52.12	69.5	86.9	104.2	121.6	139.0	156.4	191.1
11	17.40	34.80	52.20	69.6	87.0	104.4	121.8	139.2	156.6	191.4
12	17.43	34.86	52.29	69.7	87.1	104.6	122.0	139.4	156.9	191.7
13	17.46	34.91	52.37	69.8	87.3	104.7	122.2	139.6	157.1	192.0
14	17.48	34.97	52.45	69.9	87.4	104.9	122.4	139.9	157.4	192.3
15	17.51	35.02	52.53	70.0	87.6	105.1	122.6	140.1	157.6	192.6
16	17.54	35.08	52.61	70.2	87.7	105.2	122.8	140.3	157.8	192.9
17	17.56	35.13	52.70	70.3	87.8	105.4	123.0	140.5	158.1	193.2
18	17.59	35.18	52.78	70.4	88.0	105.6	123.1	140.7	158.3	193.5
19	17.62	35.24	52.86	70.5	88.1	105.7	123.3	141.0	158.6	193.8
20	17.65	35.29	52.94	70.6	88.2	105.9	123.5	141.2	158.8	194.1
21	17.67	35.35	53.02	70.7	88.4	106.0	123.7	141.4	159.1	194.4
22	17.70	35.40	53.10	70.8	88.5	106.2	123.9	141.6	159.3	194.7
23	17.73	35.46	53.18	70.9	88.6	106.4	124.1	141.8	159.6	195.0
24	17.76	35.51	53.27	71.0	88.8	106.5	124.3	142.0	159.8	195.3
25	17.78	35.56	53.35	71.1	88.9	106.7	124.5	142.3	160.0	195.6
26	17.81	35.62	53.43	71.2	89.0	106.9	124.7	142.5	160.3	195.9
27	17.84	35.67	53.51	71.4	89.2	107.0	124.9	142.7	160.5	196.2
28	17.86	35.73	53.59	71.5	89.3	107.2	125.0	142.9	160.8	196.5
29	17.89	35.78	53.67	71.6	89.5	107.4	125.2	143.1	161.0	196.8
30	17.92	35.84	53.76	71.7	89.6	107.5	125.4	143.4	161.3	197.1
31	17.95	35.89	53.84	71.8	89.7	107.7	125.6	143.6	161.5	197.4
32	17.97	35.94	53.92	71.9	89.9	107.8	125.8	143.8	161.8	197.7
33	18.00	36.00	54.00	72.0	90.0	108.0	126.0	144.0	162.0	198.0
34	18.03	36.05	54.08	72.1	90.1	108.2	126.2	144.2	162.2	198.3
35	18.05	36.11	54.16	72.2	90.3	108.3	126.4	144.4	162.5	198.6
36	18.08	36.16	54.24	72.3	90.4	108.5	126.6	144.6	162.7	198.9
37	18.11	36.22	54.33	72.4	90.5	108.6	126.8	144.9	163.0	199.2
38	18.14	36.27	54.41	72.5	90.7	108.8	127.0	145.1	163.2	199.5
39	18.16	36.32	54.49	72.6	90.8	109.0	127.1	145.3	163.5	199.8
40	18.19	36.38	54.57	72.8	91.0	109.1	127.3	145.5	163.7	200.1
41	18.22	36.43	54.65	72.9	91.1	109.3	127.5	145.7	164.0	200.4
42	18.24	36.49	54.73	73.0	91.2	109.5	127.7	146.0	164.2	200.7
43	18.27	36.54	54.81	73.1	91.4	109.6	127.9	146.2	164.4	201.0
44	18.30	36.60	54.89	73.2	91.5	109.8	128.1	146.4	164.7	201.3
45	18.32	36.65	54.98	73.3	91.6	110.0	128.3	146.6	164.9	201.6
46	18.35	36.70	55.06	73.4	91.8	110.1	128.5	146.8	165.2	201.9
47	18.38	36.76	55.14	73.5	91.9	110.3	128.6	147.0	165.4	202.2
48	18.41	36.81	55.22	73.6	92.0	110.4	128.8	147.2	165.6	202.5
49	18.43	36.87	55.30	73.7	92.2	110.6	129.0	147.5	165.9	202.8
50	18.46	36.92	55.38	73.8	92.3	110.8	129.2	147.7	166.1	203.1
51	18.49	36.98	55.46	74.0	92.4	110.9	129.4	147.9	166.4	203.4
52	18.51	37.03	55.54	74.1	92.6	111.1	129.6	148.1	166.6	203.7
53	18.54	37.08	55.62	74.2	92.7	111.2	129.8	148.3	166.9	204.0
54	18.57	37.14	55.71	74.3	92.8	111.4	130.0	148.6	167.1	204.2
55	18.60	37.19	55.79	74.4	93.0	111.6	130.2	148.8	167.4	204.6
56	18.62	37.24	55.87	74.5	93.1	111.7	130.4	149.0	167.6	204.8
57	18.65	37.30	55.95	74.6	93.2	111.9	130.6	149.2	167.8	205.1
58	18.68	37.35	56.03	74.7	93.4	112.1	130.7	149.4	168.1	205.4
59	18.70	37.41	56.11	74.8	93.5	112.2	130.9	149.6	168.3	205.7
Horz. Dist.	96.68	193.4	290.0	386.7	483.4	580	677	773	870	1064

TABLE III.—(*Continued*)

11°

′	100	200	300	400	500	600	700	800	900	1100
0	18.73	37.46	56.19	74.9	93.6	112.4	131.1	149.8	168.6	206.0
1	18.76	37.52	56.27	75.0	93.8	112.6	131.3	150.1	168.8	206.3
2	18.78	37.57	56.36	75.1	93.9	112.7	131.5	150.3	169.1	206.6
3	18.81	37.62	56.43	75.2	94.1	112.9	131.7	150.5	169.3	206.9
4	18.84	37.68	56.51	75.4	94.2	113.0	131.9	150.7	169.5	207.2
5	18.86	37.73	56.60	75.5	94.3	113.2	132.1	150.9	169.8	207.5
6	18.89	37.78	56.68	75.6	94.5	113.4	132.2	151.1	170.0	207.8
7	18.92	37.84	56.76	75.7	94.6	113.5	132.4	151.4	170.3	208.1
8	18.95	37.89	56.84	75.8	94.7	113.7	132.6	151.6	170.5	208.4
9	18.97	37.95	56.92	75.9	94.9	113.8	132.8	151.8	170.8	208.7
10	19.00	38.00	57.00	76.0	95.0	114.0	133.0	152.0	171.0	209.0
11	19.03	38.05	57.08	76.1	95.1	114.2	133.2	152.2	171.2	209.3
12	19.05	38.11	57.16	76.2	95.3	114.3	133.4	152.4	171.5	209.6
13	19.08	38.16	57.24	76.3	95.4	114.5	133.6	152.6	171.7	209.9
14	19.11	38.22	57.32	76.4	95.5	114.6	133.8	152.9	172.0	210.2
15	19.13	38.27	57.40	76.5	95.7	114.8	133.9	153.1	172.2	210.5
16	19.16	38.32	57.48	76.6	95.8	115.0	134.1	153.3	172.4	210.8
17	19.19	38.38	57.56	76.8	95.9	115.1	134.3	153.5	172.7	211.1
18	19.22	38.43	57.64	76.9	96.1	115.3	134.5	153.7	172.9	211.4
19	19.24	38.48	57.72	77.0	96.2	115.4	134.7	153.9	173.2	211.7
20	19.27	38.54	57.81	77.1	96.3	115.6	134.9	154.2	173.4	212.0
21	19.30	38.59	57.89	77.2	96.5	115.8	135.1	154.4	173.7	212.2
22	19.32	38.64	57.97	77.3	96.6	115.9	135.2	154.6	173.9	212.5
23	19.35	38.70	58.05	77.4	96.8	116.1	135.4	154.8	174.1	212.8
24	19.38	38.75	58.13	77.5	96.9	116.3	135.6	155.0	174.4	213.1
25	19.40	38.80	58.21	77.6	97.0	116.4	135.8	155.2	174.6	213.4
26	19.43	38.86	58.29	77.7	97.2	116.6	136.0	155.4	174.9	213.7
27	19.46	38.91	58.37	77.8	97.3	116.7	136.2	155.6	175.1	214.0
28	19.48	38.97	58.45	77.9	97.4	116.9	136.4	155.9	175.4	214.3
29	19.51	39.02	58.53	78.0	97.6	117.1	136.6	156.1	175.6	214.6
30	19.54	39.07	58.61	78.2	97.7	117.2	136.8	156.3	175.8	214.9
31	19.56	39.13	58.69	78.2	97.8	117.4	136.9	156.5	176.1	215.2
32	19.59	39.18	58.77	78.4	98.0	117.5	137.1	156.7	176.3	215.5
33	19.62	39.23	58.85	78.5	98.1	117.7	137.3	156.9	176.6	215.8
34	19.64	39.29	58.93	78.6	98.2	117.9	147.5	157.2	176.8	216.1
35	19.67	39.34	59.01	78.7	98.4	118.0	137.7	157.4	177.0	216.4
36	19.70	39.39	59.09	78.8	98.5	118.2	137.9	157.6	177.3	216.7
37	19.72	39.45	59.17	78.9	98.6	118.3	138.1	157.8	177.5	217.0
38	19.75	39.50	59.25	79.0	98.8	118.5	138.2	158.0	177.8	217.3
39	19.78	39.56	59.33	79.1	98.9	118.7	138.4	158.2	178.0	217.6
40	19.80	39.61	59.41	79.2	99.0	118.8	138.6	158.4	178.2	217.8
41	19.83	39.66	59.49	79.3	99.2	119.0	138.8	158.6	178.5	218.1
42	19.86	39.72	59.57	79.4	99.3	119.2	139.0	158.9	178.7	218.4
43	19.88	39.77	59.65	79.5	99.4	119.3	139.2	159.1	179.0	218.7
44	19.91	39.82	59.73	79.6	99.6	119.5	139.4	159.3	179.2	219.0
45	19.94	39.88	59.81	79.8	99.7	119.6	139.6	159.5	179.4	219.3
46	19.96	39.93	59.89	79.9	99.8	119.8	139.8	159.7	179.7	219.6
47	19.99	39.98	59.97	80.0	100.0	120.0	139.9	159.9	179.9	219.9
48	20.02	40.04	60.05	80.1	100.1	120.1	140.1	160.1	180.2	220.2
49	20.04	40.09	60.13	80.2	100.2	120.3	140.3	160.4	180.4	220.5
50	20.07	40.14	60.21	80.3	100.4	120.4	140.5	160.6	180.6	220.8
51	20.10	40.20	60.29	80.4	100.5	120.6	140.7	160.8	180.9	221.1
52	20.12	40.25	60.37	80.5	100.6	120.7	140.9	161.0	181.1	221.4
53	20.15	40.30	60.45	80.6	100.8	120.9	141.0	161.2	181.4	221.7
54	20.18	40.36	60.53	80.7	100.9	121.1	141.2	161.4	181.6	222.0
55	20.20	40.41	60.61	80.8	101.0	121.2	141.4	161.6	181.8	222.2
56	20.23	40.46	60.69	80.9	101.2	121.4	141.6	161.8	182.1	222.5
57	20.26	40.51	60.77	81.0	101.3	121.5	141.8	162.1	182.3	222.8
58	20.28	40.57	60.85	81.1	101.4	121.7	142.0	162.3	182.6	223.1
59	20.31	40 62	60.93	81.2	101.6	121.9	142.2	162.5	182.8	223.4
Horz. Dist.	96 03	192.1	288.1	384.1	480.2	576	672	768	864	1056

TABLE III.—(*Continued*)

12°

′	100	200	300	400	500	600	700	800	900	1100
0	20.34	40.67	61.01	81.3	101.7	122.0	142.4	162.7	183.0	223.7
1	20.36	40.73	61.09	81.4	101.8	122.2	142.5	162.9	183.3	224.0
2	20.39	40.78	61.17	81.6	102.0	122.3	142.7	163.1	183.5	224.3
3	20.42	40.83	61.25	81.7	102.1	122.5	142.9	163.3	183.7	224.6
4	20.44	40.89	61.33	81.8	102.2	122.7	143.1	163.5	184.0	224.9
5	20.47	40.94	61.41	81.9	102.4	122.8	143.3	163.8	184.2	225.2
6	20.50	40.99	61.49	82.0	102.5	123.0	143.5	164.0	184.5	225.5
7	20.52	41.04	61.57	82.1	102.6	123.1	143.7	164.2	184.7	225.8
8	20.55	41.10	61.65	82.2	102.8	123.3	143.8	164.4	184.9	226.0
9	20.58	41.15	61.73	82.3	102.9	123.4	144.0	164.6	185.2	226.3
10	20.60	41.20	61.81	82.4	103.0	123.6	144.2	164.8	185.4	226.6
11	20.63	41.26	61.89	82.5	103.1	123.8	144.4	165.0	185.7	226.9
12	20.66	41.31	61.97	82.6	103.3	123.9	144.6	165.2	185.9	227.2
13	20.68	41.36	62.04	82.7	103.4	124.1	144.8	165.4	186.1	227.5
14	20.71	41.42	62.12	82.8	103.5	124.2	145.0	165.7	186.4	227.8
15	20.73	41.47	62.20	82.9	103.7	124.4	145.1	165.9	186.6	228.1
16	20.76	41.52	62.28	83.0	103.8	124.6	145.3	166.1	186.8	228.4
17	20.79	41.58	62.36	83.2	103.9	124.7	145.5	166.3	187.1	228.7
18	20.81	41.63	62.44	83.3	104.1	124.9	145.7	166.5	187.3	229.0
19	20.84	41.68	62.52	83.4	104.2	125.0	145.9	166.7	187.6	229.2
20	20.87	41.73	62.60	83.5	104.3	125.2	146.1	166.9	187.8	229.5
21	20.89	41.79	62.68	83.6	104.5	125.4	146.2	167.2	188.0	229.8
22	20.92	41.84	62.76	83.7	104.6	125.5	146.4	167.4	188.3	230.1
23	20.95	41.89	62.84	83.8	104.7	125.7	146.6	167.6	188.5	230.4
24	20.97	41.94	62.92	83.9	104.9	125.8	146.8	167.8	188.8	230.7
25	21.00	42.00	63.00	84.0	105.0	126.0	147.0	168.0	189.0	231.0
26	21.03	42.05	63.08	84.1	105.1	126.2	147.2	168.2	189.2	231.3
27	21.05	42.10	63.16	84.2	105.3	126.3	147.4	168.4	189.5	231.6
28	21.08	42.16	63.23	84.3	105.4	126.5	147.6	168.6	189.7	231.9
29	21.10	42.21	63.31	84.4	105.5	126.6	147.7	168.8	189.9	232.2
30	21.13	42.26	63.39	84.5	105.7	126.8	147.9	169.0	190.2	232.4
31	21.16	42.32	63.47	84.6	105.8	127.0	148.1	169.3	190.4	232.7
32	21.18	42.37	63.55	84.7	105.9	127.1	148.3	169.5	190.6	233.0
33	21.21	42.42	63.63	84.8	106.0	127.3	148.5	169.7	190.9	233.3
34	21.24	42.47	63.71	85.0	106.2	127.4	148.7	169.9	191.1	233.6
35	21.26	42.52	63.79	85.0	106.3	127.6	148.8	170.1	191.4	233.9
36	21.29	42.58	63.87	85.2	106.4	127.7	149.0	170.3	191.6	234.2
37	21.32	42.63	63.95	85.3	106.6	127.9	149.2	170.5	191.8	234.5
38	21.34	42.68	64.02	85.4	106.7	128.0	149.4	170.7	192.1	234.8
39	21.37	42.74	64.10	85.5	106.8	128.2	149.6	170.9	192.3	235.0
40	21.39	42.79	64.18	85.6	107.0	128.4	149.8	171.2	192.6	235.3
41	21.42	42.84	64.26	85.7	107.1	128.5	149.9	171.4	192.8	235.6
42	21.45	42.89	64.34	85.8	107.2	128.7	150.1	171.6	193.0	235.9
43	21.47	42.95	64.42	85.9	107.4	128.8	150.3	171.8	193.3	236.2
44	21.50	43.00	64.50	86.0	107.5	129.0	150.5	172.0	193.5	236.5
45	21.53	43.05	64.58	86.1	107.6	129.2	150.7	172.2	193.7	236.8
46	21.55	43.10	64.66	86.2	107.8	129.3	150.9	172.4	194.0	237.1
47	21.58	43.16	64.73	86.3	107.9	129.5	151.0	172.6	194.2	237.4
48	21.60	43.21	64.81	86.4	108.0	129.6	151.2	172.8	194.4	237.6
49	21.63	43.26	64.89	86.5	108.2	129.8	151.4	173.0	194.7	237.9
50	21.66	43.31	64.97	86.6	108.3	129.9	151.6	173.2	194.9	238.2
51	21.68	43.37	65.05	86.7	108.4	130.1	151.8	173.5	195.2	238.5
52	21.71	43.42	65.13	86.8	108.6	130.2	152.0	173.7	195.4	238.8
53	21.74	43.47	65.21	86.9	108.7	130.4	152.2	173.9	195.6	239.1
54	21.76	43.52	65.28	87.0	108.8	130.6	152.3	174.1	195.8	239.4
55	21.79	43.58	65.36	87.2	108.9	130.7	152.5	174.3	196.1	239.7
56	21.81	43.63	65.44	87.3	109.1	130.9	152.7	174.5	196.3	240.0
57	21.84	43.68	65.52	87.4	109.2	131.0	152.9	174.7	196.6	240.2
58	21.87	43.73	65.60	87.5	109.3	131.2	153.1	174.9	196.8	240.5
59	21.89	43.78	65.68	87.6	109.5	131.4	153.2	175.1	197.0	240.8
Horz. Dist.	95.32	190.6	286.0	381.3	476.6	572	667	763	858	1048

TABLE III.—(*Continued*)

13°

′	100	200	300	400	500	600	700	800	900	1100
0	21.92	43.84	65.76	87.7	109.6	131.5	153.4	175.4	197.3	241.1
1	21.94	43.89	65.83	87.8	109.7	131.7	153.6	175.6	197.5	241.4
2	21.97	43.94	65.91	87.9	109.9	131.8	153.8	175.8	197.7	241.7
3	22.00	43.99	65.99	88.0	110.0	132.0	154.0	176.0	198.0	242.0
4	22.02	44.05	66.07	88.1	110.1	132.1	154.2	176.2	198.2	242.2
5	22.05	44.10	66.15	88.2	110.2	132.3	154.3	176.4	198.4	242.5
6	22.08	44.15	66.23	88.3	110.4	132.4	154.5	176.6	198.7	242.8
7	22.10	44.20	66.30	88.4	110.5	132.6	154.7	176.8	198.9	243.1
8	22.13	44.26	66.38	88.5	110.6	132.8	154.9	177.0	199.2	243.4
9	22.15	44.31	66.46	88.6	110.8	132.9	155.1	177.2	199.4	243.7
10	22.18	44.36	66.54	88.7	110.9	133.1	155.3	177.4	199.6	244.0
11	22.21	44.41	66.62	88.8	111.0	133.2	155.4	177.6	199.8	244.3
12	22.23	44.46	66.70	88.9	111.2	133.4	155.6	177.9	200.1	244.6
13	22.26	44.52	66.77	89.0	111.3	133.6	155.8	178.1	200.3	244.8
14	22.28	44.57	66.85	89.1	111.4	133.7	156.0	178.3	200.6	245.1
15	22.31	44.62	66.93	89.2	111.6	133.9	156.2	178.5	200.8	245.4
16	22.34	44.67	67.01	89.3	111.7	134.0	156.4	178.7	201.0	245.7
17	22.36	44.72	67.09	89.4	111.8	134.2	156.5	178.9	201.3	246.0
18	22.39	44.78	67.16	89.6	111.9	134.3	156.7	179.1	201.5	246.3
19	22.41	44.83	67.24	89.7	112.1	134.5	156.9	179.3	201.7	246.6
20	22.44	44.88	67.32	89.8	112.2	134.6	157.1	179.5	202.0	246.8
21	22.47	44.93	67.40	89.9	112.3	134.8	157.3	179.7	202.2	247.1
22	22.49	44.98	67.48	90.0	112.5	135.0	157.4	179.9	202.4	247.4
23	22.52	45.04	67.55	90.1	112.6	135.1	157.6	180.1	202.7	247.7
24	22.54	45.09	67.63	90.2	112.7	135.3	157.8	180.4	202.9	248.0
25	22.57	45.14	67.71	90.3	112.8	135.4	158.0	180.6	203.1	248.3
26	22.60	45.19	67.79	90.4	113.0	135.6	158.2	180.8	203.4	248.6
27	22.62	45.24	67.86	90.5	113.1	135.7	158.4	181.0	203.6	248.8
28	22.65	45.30	67.94	90.6	113.2	135.9	158.5	181.2	203.8	249.1
29	22.67	45.35	68.02	90.7	113.4	136.0	158.7	181.4	204.1	249.4
30	22.70	45.40	68.10	90.8	113.5	136.2	158.9	181.6	204.3	249.7
31	22.73	45.45	68.18	90.9	113.6	136.4	159.1	181.8	204.5	250.0
32	22.75	45.50	68.25	91.0	113.8	136.5	159.3	182.0	204.8	250.3
33	22.78	45.55	68.33	91.1	113.9	136.7	159.4	182.2	205.0	250.6
34	22.80	45.61	68.41	91.2	114.0	136.8	159.6	182.4	205.2	250.8
35	22.83	45.66	68.49	91.3	114.1	137.0	159.8	182.6	205.5	251.1
36	22.86	45.71	68.56	91.4	114.3	137.1	160.0	182.8	205.7	251.4
37	22.88	45.76	68.64	91.5	114.4	137.3	160.2	183.0	205.9	251.7
38	22.91	45.81	68.72	91.6	114.5	137.4	160.4	183.2	206.2	252.0
39	22.94	45.88	68.81	91.8	114.7	137.6	160.6	183.5	206.4	252.3
40	22.96	45.92	68.88	91.8	114.8	137.8	160.7	183.7	206.6	252.5
41	22.98	45.97	68.95	91.9	114.9	137.9	160.9	183.9	206.9	252.8
42	23.01	46.02	69.03	92.0	115.0	138.1	161.1	184.1	207.1	253.1
43	23.04	46.07	69.11	92.1	115.2	138.2	161.2	184.3	207.3	253.4
44	23.06	46.12	69.18	92.2	115.3	138.4	161.4	184.5	207.6	253.7
45	23.09	46.18	69.26	92.4	115.4	138.5	161.6	184.7	207.8	254.0
46	23.11	46.23	69.34	92.4	115.6	138.7	161.8	184.9	208.0	254.2
47	23.14	46.28	69.42	92.6	115.7	138.8	162.0	185.1	208.2	254.5
48	23.15	46.30	69.46	92.6	115.8	138.9	162.1	185.2	208.4	254.7
49	23.19	46.38	69.57	92.8	116.0	139.1	162.3	185.5	208.7	255.1
50	23.22	46.43	69.65	92.9	116.1	139.3	162.5	185.7	209.0	255.4
51	23.24	46.48	69.73	93.0	116.2	139.4	162.7	185.9	209.2	255.7
52	23.27	46.54	69.81	93.1	116.3	139.6	162.9	186.2	209.4	256.0
53	23.29	46.59	69.88	93.2	116.5	139.8	163.0	186.4	209.6	256.2
54	23.32	46.64	69.96	93.3	116.6	139.9	163.2	186.6	209.9	256.5
55	23.34	46.69	70.04	93.4	116.7	140.1	163.4	186.8	210.1	256.8
56	23.37	46.74	70.11	93.5	116.9	140.2	163.6	187.0	210.3	257.1
57	23.40	46.79	70.19	93.6	117.0	140.4	163.8	187.2	210.6	257.4
58	23.42	46.84	70.27	93.7	117.1	140.5	164.0	187.4	210.8	257.6
59	23.45	46.90	70.34	93.8	117.2	140.7	164.1	187.6	211.0	257.9
Horz. Dist.	94.55	189.1	283.6	378.2	472.8	567	662	756	851	1040

14°

′	100	200	300	400	500	600	700	800	900	1100
0	23.47	47.00	70.42	93.9	117.4	140.8	164.3	187.8	211.3	258.2
1	23.50	47.00	70.50	94.0	117.5	141.0	164.5	188.0	211.5	258.5
2	23.52	47.05	70.58	94.1	117.6	141.2	164.7	188.2	211.7	258.8
3	23.55	47.10	70.65	94.2	117.8	141.3	164.8	188.4	212.0	259.1
4	23.58	47.15	70.73	94.3	117.9	141.5	165.0	188.6	212.2	259.3
5	23.60	47.20	70.81	94.4	118.0	141.6	165.2	188.8	212.4	259.6
6	23.63	47.25	70.88	94.5	118.1	141.8	165.4	189.0	212.6	259.9
7	23.65	47.31	70.96	94.6	118.3	141.9	165.6	189.2	212.9	260.2
8	23.68	47.36	71.04	94.7	118.4	142.1	165.8	189.4	213.1	260.5
9	23.70	47.41	71.11	94.8	118.5	142.2	165.9	189.6	213.3	260.8
10	23.73	47.46	71.19	94.9	118.6	142.4	166.1	189.8	213.6	261.0
11	23.76	47.51	71.27	95.0	118.8	142.5	166.3	190.0	213.8	261.3
12	23.78	47.56	71.34	95.1	118.9	142.7	166.5	190.2	214.0	261.6
13	23.81	47.61	71.42	95.2	119.0	142.8	166.6	190.5	214.3	261.9
14	23.83	47.66	71.50	95.3	119.2	143.0	166.8	190.7	214.5	262.2
15	23.86	47.72	71.57	95.4	119.3	143.2	167.0	190.9	214.7	262.4
16	23.88	47.77	71.65	95.5	119.4	143.3	167.2	191.1	215.0	262.7
17	23.91	47.82	71.73	95.6	119.6	143.4	167.4	191.3	215.2	263.0
18	23.94	47.87	71.80	95.7	119.7	143.6	167.5	191.5	215.4	263.3
19	23.96	47.92	71.88	95.8	119.8	143.8	167.7	191.7	215.6	263.6
20	23.98	47.97	72.00	95.9	119.9	143.9	167.9	191.9	215.9	263.8
21	24.01	48.02	72.03	96.0	120.1	144.1	168.1	192.1	216.1	264.1
22	24.04	48.07	72.11	96.2	120.2	144.2	168.3	192.3	216.3	264.4
23	24.06	48.12	72.19	96.2	120.3	144.4	168.4	192.5	216.6	264.7
24	24.09	48.18	72.26	96.4	120.4	144.5	168.6	192.7	216.8	265.0
25	24.11	48.23	72.34	96.4	120.6	144.7	168.8	192.9	217.0	265.2
26	24.14	48.28	72.42	96.6	120.7	144.8	169.0	193.1	217.2	265.5
27	24.16	48.33	72.49	96.7	120.8	145.0	169.2	193.3	217.5	265.8
28	24.19	48.38	72.57	96.8	121.0	145.1	169.3	193.5	217.7	266.1
29	24.22	48.43	72.64	96.9	121.1	145.3	169.5	193.7	217.9	266.4
30	24.24	48.48	72.72	97.0	121.2	145.4	169.7	193.9	218.2	266.6
31	24.27	48.53	72.80	97.1	121.3	145.6	169.9	194.1	218.4	266.9
32	24.29	48.58	72.88	97.2	121.5	145.8	170.0	194.3	218.6	267.2
33	24.32	48.63	72.95	97.3	121.6	145.9	170.2	194.5	218.8	267.5
34	24.34	48.68	73.03	97.4	121.7	146.0	170.4	194.7	219.1	267.8
35	24.37	48.74	73.10	97.5	121.8	146.2	170.6	194.9	219.3	268.0
36	24.39	48.79	73.18	97.6	122.0	146.4	170.8	195.1	219.5	268.3
37	24.42	48.84	73.26	97.7	122.1	146.5	170.9	195.4	219.8	268.6
38	24.44	48.89	73.33	97.8	122.2	146.7	171.1	195.6	220.0	268.9
39	24.47	48.94	73.41	97.9	122.4	146.8	171.3	195.8	220.2	269.2
40	24.50	48.99	73.48	98.0	122.5	147.0	171.5	196.0	220.4	269.4
41	24.52	49.04	73.56	98.1	122.6	147.1	171.6	196.2	220.7	269.7
42	24.54	49.09	73.64	98.2	122.7	147.3	171.8	196.4	220.9	270.0
43	24.57	49.14	73.71	98.3	122.8	147.4	172.0	196.6	221.1	270.3
44	24.60	49.19	73.79	98.4	123.0	147.6	172.2	196.8	221.4	270.6
45	24.62	49.24	73.86	98.5	123.1	147.7	172.4	197.0	221.6	270.8
46	24.65	49.29	73.94	98.6	123.2	147.9	172.5	197.2	221.8	271.1
47	24.67	49.34	74.02	98.7	123.4	148.0	172.7	197.4	222.1	271.4
48	24.70	49.39	74.09	98.8	123.5	148.2	172.9	197.6	222.3	271.7
49	24.72	49.44	74.17	98.9	123.6	148.3	173.1	197.8	222.5	272.0
50	24.75	49.50	74.24	99.0	123.7	148.5	173.2	198.0	222.7	272.2
51	24.77	49.55	74.32	99.1	123.9	148.6	173.4	198.2	223.0	272.5
52	24.80	49.60	74.39	99.2	124.0	148.8	173.6	198.4	223.2	272.8
53	24.82	49.65	74.47	99.3	124.1	148.9	173.8	198.6	223.4	273.1
54	24.85	49.70	74.55	99.4	124.2	149.1	173.9	198.8	223.6	273.3
55	24.87	49.75	74.62	99.5	124.4	149.2	174.1	199.0	223.9	273.6
56	24.90	49.80	74.70	99.6	124.5	149.4	174.3	199.2	224.1	273.9
57	24.92	49.85	74.77	99.7	124.6	149.6	174.5	199.4	224.3	274.2
58	24.95	49.90	74.85	99.8	124.8	149.7	174.6	199.6	224.6	274.4
59	24.98	49.95	74.92	99.9	124.9	149.8	174.8	199.8	224.8	274.7
Horz. Dist.	93.73	187.5	281.2	374.9	468.6	562	656	750	844	1031

15°

′	100	200	300	400	500	600	700	800	900	1100
0	25.00	50.00	75.00	100.0	125.0	150.0	175.0	200.0	225.0	275.0
1	25.02	50.05	75.08	100.1	125.2	150.2	175.2	200.2	225.3	275.3
2	25.05	50.10	75.15	100.2	125.2	150.3	175.4	200.4	225.5	275.6
3	25.08	50.15	75.23	100.3	125.4	150.4	175.5	200.6	225.7	275.8
4	25.10	50.20	75.30	100.4	125.5	150.6	175.7	200.8	225.9	276.1
5	25.13	50.25	75.38	100.5	125.6	150.8	175.9	201.0	226.1	276.4
6	25.15	50.30	75.45	100.6	125.8	150.9	176.0	201.2	226.4	276.6
7	25.18	50.35	75.53	100.7	125.9	151.1	176.2	201.4	226.6	276.9
8	25.20	50.40	75.60	100.8	126.0	151.2	176.4	201.6	226.8	277.2
9	25.23	50.45	75.68	100.9	126.1	151.4	176.6	201.8	227.0	277.5
10	25.25	50.50	75.76	101.0	126.3	151.5	176.8	202.0	227.3	277.8
11	25.28	50.55	75.83	101.1	126.4	151.7	176.9	202.2	227.5	278.0
12	25.30	50.60	75.90	101.2	126.5	151.8	177.1	202.4	227.7	278.3
13	25.33	50.65	75.98	101.3	126.6	152.0	177.3	202.6	227.9	278.6
14	25.35	50.70	76.06	101.4	126.8	152.1	177.5	202.8	228.2	278.9
15	25.38	50.75	76.13	101.5	126.9	152.3	177.6	203.0	228.4	279.2
16	25.40	50.80	76.21	101.6	127.0	152.4	177.8	203.2	228.6	279.4
17	25.43	50.85	76.28	101.7	127.1	152.6	178.0	203.4	228.8	279.7
18	25.45	50.90	76.36	101.8	127.3	152.7	178.2	203.6	229.1	280.0
19	25.48	50.95	76.43	101.9	127.4	152.9	178.3	203.8	229.3	280.2
20	25.50	51.00	76.51	102.0	127.5	153.0	178.5	204.0	229.5	280.5
21	25.53	51.05	76.58	102.1	127.6	153.2	178.7	204.2	229.7	280.8
22	25.55	51.10	76.66	102.2	127.8	153.3	178.9	204.4	230.0	281.1
23	25.58	51.15	76.73	102.3	127.9	153.5	179.0	204.6	230.2	281.2
24	25.60	51.20	76.81	102.4	128.0	153.6	179.2	204.8	230.4	281.6
25	25.63	51.25	76.88	102.5	128.1	153.8	179.4	205.0	230.6	281.9
26	25.65	51.30	76.95	102.6	128.3	153.9	179.6	205.2	230.9	282.2
27	25.68	51.35	77.03	102.7	128.4	154.1	179.7	205.4	231.1	282.4
28	25.70	51.40	77.11	102.8	128.5	154.2	179.9	205.6	231.3	282.7
29	25.73	51.45	77.18	102.9	128.6	154.4	180.1	205.8	231.5	283.0
30	25.75	51.50	77.26	103.0	128.8	154.5	180.3	206.0	231.8	283.3
31	25.78	51.55	77.33	103.1	128.9	154.7	180.4	206.2	232.0	283.6
32	25.80	51.60	77.41	103.2	129.0	154.8	180.6	206.4	232.2	283.8
33	25.83	51.65	77.48	103.3	129.1	155.0	180.8	206.6	232.4	284.1
34	25.85	51.70	77.56	103.4	129.3	155.1	181.0	206.8	232.7	284.4
35	25.88	51.75	77.63	103.5	129.4	155.3	181.1	207.0	232.9	284.6
36	25.90	51.80	77.70	103.6	129.5	155.4	181.3	207.2	233.1	284.9
37	25.93	51.85	77.78	103.7	129.6	155.6	181.5	207.4	233.3	285.2
38	25.95	51.90	77.85	103.8	129.8	155.7	181.7	207.6	233.6	285.5
39	25.98	51.95	77.93	103.9	129.9	155.9	181.8	207.8	233.8	285.7
40	26.00	52.00	78.00	104.0	130.0	156.0	182.0	208.0	234.0	286.0
41	26.02	52.05	78.08	104.1	130.2	156.2	182.2	208.2	234.3	286.3
42	26.05	52.10	78.15	104.2	130.2	156.3	182.4	208.4	234.5	286.6
43	26.08	52.15	78.23	104.3	130.4	156.4	182.5	208.6	234.7	286.8
44	26.10	52.20	78.30	104.4	130.5	156.6	182.7	208.8	234.9	287.1
45	26.12	52.25	78.38	104.5	130.6	156.8	182.9	209.0	235.1	287.4
46	26.15	52.30	78.45	104.6	130.8	156.9	183.0	209.2	235.4	287.6
47	26.18	52.35	78.52	104.7	130.9	157.0	183.2	209.4	235.6	287.9
48	26.20	52.40	78.60	104.8	131.0	157.2	183.4	209.6	235.8	288.2
49	26.22	52.45	78.67	104.9	131.1	157.3	183.6	209.8	236.0	288.5
50	26.25	52.50	78.75	105.0	131.2	157.5	183.7	210.0	236.2	288.7
51	26.27	52.55	78.82	105.1	131.4	157.6	183.9	210.2	236.5	289.0
52	26.30	52.60	78.90	105.2	131.5	157.8	184.1	210.4	236.7	289.3
53	26.32	52.65	78.97	105.3	131.6	157.9	184.3	210.6	236.9	289.6
54	26.35	52.70	79.04	105.4	131.7	158.1	184.4	210.8	237.1	289.8
55	26.37	52.74	79.12	105.5	131.9	158.2	184.6	211.0	237.4	290.1
56	26.40	52.79	79.19	105.6	132.0	158.4	184.8	211.2	237.6	290.4
57	26.42	52.84	79.27	105.7	132.1	158.5	185.0	211.4	237.8	290.6
58	26.45	52.89	79.34	105.8	132.2	158.7	185.1	211.6	238.0	290.9
59	26.47	52.94	79.42	105.9	132.4	158.8	185.3	211.8	238.2	291.2
Horz. Dist.	92.86	185.7	278.6	371.4	464.3	557	650	743	836	1022

TABLE III.—(*Continued*)

16°

′	100	200	300	400	500	600	700	800	900	1100
0	26.50	52.99	79.45	106.0	132.5	159.0	185.5	212.0	238.5	291.5
1	26.52	53.04	79.56	106.1	132.6	159.1	185.6	212.2	238.7	291.7
2	26.55	53.09	79.64	106.2	132.7	159.3	185.8	212.4	238.9	292.0
3	26.57	53.14	79.71	106.3	132.8	159.4	186.0	212.6	239.1	292.3
4	26.60	53.19	79.78	106.4	133.0	159.6	186.2	212.8	239.4	292.5
5	26.62	53.24	79.86	106.5	133.1	159.7	186.3	213.0	239.6	292.8
6	26.64	53.29	79.90	106.6	133.2	159.9	186.5	213.2	239.8	293.1
7	26.67	53.34	80.01	106.7	133.3	160.0	186.7	213.4	240.0	293.4
8	26.69	53.39	80.08	106.8	133.5	160.2	186.8	213.5	240.2	293.6
9	26.72	53.44	80.15	106.9	133.6	160.3	187.0	213.7	240.5	293.9
10	26.74	53.48	80.23	107.0	133.7	160.4	187.2	213.9	240.7	294.2
11	26.77	53.53	80.30	107.1	133.8	160.6	187.4	214.1	240.9	294.4
12	26.79	53.58	80.38	107.2	134.0	160.8	187.5	214.3	241.1	294.7
13	26.82	53.63	80.45	107.3	134.1	160.9	187.7	214.5	241.3	295.0
14	26.84	53.68	80.52	107.4	134.2	161.0	187.9	214.7	241.6	295.2
15	26.86	53.73	80.60	107.5	134.3	161.2	188.1	214.9	241.8	295.5
16	26.89	53.78	80.67	107.6	134.4	161.3	188.2	215.1	242.0	295.8
17	26.91	53.83	80.74	107.7	134.6	161.5	188.4	215.3	242.2	296.0
18	26.94	53.88	80.82	107.8	134.7	161.6	188.6	215.5	242.4	296.3
19	26.96	53.93	80.89	107.8	134.8	161.8	188.7	215.7	242.7	296.6
20	26.99	53.98	80.96	108.0	134.9	161.9	188.9	215.9	242.9	296.9
21	27.01	54.02	81.04	108.0	135.1	162.1	189.1	216.1	243.1	297.1
22	27.04	54.07	81.11	108.2	135.2	162.2	189.3	216.3	243.3	297.4
23	27.06	54.12	81.18	108.2	135.3	162.4	189.4	216.5	243.6	297.7
24	27.09	54.17	81.26	108.3	135.4	162.5	189.6	216.7	243.8	297.9
25	27.11	54.22	81.33	108.4	135.6	162.7	189.8	216.9	244.0	298.2
26	27.13	54.26	81.40	108.5	135.6	162.8	189.9	217.0	244.2	298.4
27	27.16	54.32	81.48	108.6	135.8	163.0	190.1	217.3	244.4	298.7
28	27.18	54.37	81.55	108.7	135.9	163.1	190.3	217.5	244.6	299.0
29	27.21	54.41	81.62	108.8	136.0	163.2	190.4	217.7	244.9	299.3
30	27.23	54.46	81.70	108.9	136.2	163.4	190.6	217.9	245.1	299.6
31	27.26	54.51	81.77	109.0	136.3	163.5	190.8	218.0	245.3	299.8
32	27.28	54.56	81.84	109.1	136.4	163.7	191.0	218.2	245.5	300.1
33	27.30	54.61	81.92	109.2	136.5	163.8	191.1	218.4	245.8	300.4
34	27.33	54.66	81.99	109.3	136.6	164.0	191.3	218.6	246.0	300.6
35	27.35	54.71	82.10	109.4	136.8	164.1	191.5	218.8	246.2	300.9
36	27.38	54.76	82.13	109.5	136.9	164.3	191.6	219.0	246.4	301.2
37	27.40	54.80	82.21	109.6	137.0	164.4	191.8	219.2	246.6	301.4
38	27.43	54.85	82.28	109.7	137.1	164.6	192.0	219.4	246.8	301.7
39	27.45	54.90	82.35	109.8	137.3	164.7	192.2	219.6	247.1	302.0
40	27.48	54.95	82.43	109.9	137.4	164.8	192.3	219.8	247.3	302.2
41	27.50	55.00	82.50	110.0	137.5	165.0	192.5	220.0	247.5	302.5
42	27.52	55.05	82.57	110.1	137.6	165.1	192.7	220.2	247.7	302.8
43	27.55	55.10	82.60	110.2	137.7	165.3	192.8	220.4	247.9	303.0
44	27.57	55.14	82.72	110.3	137.9	165.4	193.0	220.6	248.2	303.3
45	27.60	55.19	82.79	110.4	138.0	165.6	193.2	220.8	248.4	303.6
46	27.62	55.24	82.86	110.5	138.1	165.7	193.4	221.0	248.6	303.8
47	27.65	55.29	82.94	110.6	138.2	165.9	193.5	221.2	248.8	304.1
48	27.67	55.34	83.01	110.7	138.4	166.0	193.7	221.4	249.0	304.4
49	27.69	55.39	83.08	110.8	138.5	166.2	193.9	221.6	249.2	304.6
50	27.72	55.44	83.15	110.9	138.6	166.3	194.0	221.7	249.5	304.9
51	27.74	55.48	83.23	111.0	138.7	166.4	194.2	221.9	249.7	305.2
52	27.77	55.53	83.30	111.1	138.8	166.6	194.4	222.1	249.9	305.4
53	27.79	55.58	83.37	111.2	139.0	166.7	194.5	222.3	250.1	305.7
54	27.82	55.63	83.44	111.3	139.1	166.9	194.7	222.5	250.3	306.0
55	27.84	55.68	83.52	111.4	139.2	167.0	194.9	222.7	250.6	306.2
56	27.86	55.73	83.59	111.4	139.3	167.2	195.0	222.9	250.8	306.5
57	27.89	55.78	83.66	111.6	139.4	167.3	195.2	223.1	251.0	306.8
58	27.91	55.82	83.74	111.6	139.6	167.5	195.4	223.3	251.2	307.0
59	27.94	55.87	83.81	111.7	139.7	167.6	195.6	223.5	251.4	307.3
Horz. Dist.	91.93	183.9	275.8	367.7	459.7	552	644	735	827	1011

TABLE III.—(*Continued*)

NOTE.—The values given on this page are for 100 feet only. To obtain difference of elevation for any other distance, multiply tabular value for given angle by observed stadia intercept. Example: Vertical angle 19° 22,. Observed stadia intercept 3.20 feet. 31.28 × 3.20 = 100.09 feet = correct difference of elevation required.

′	17°	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	′
0	27.96	29.39	30.78	32.14	33.46	34.73	35.97	37.16	38.30	39.40	40.45	41.45	42.40	0
1	27.99	29.42	30.81	32.16	33.48	34.75	35.99	37.18	38.32	39.42	40.47	41.47	42.42	1
2	28.01	29.44	30.83	32.18	33.50	34.77	36.01	37.20	38.34	39.44	40.49	41.48	42.43	2
3	28.04	29.47	30.85	32.21	33.52	34.80	36.03	37.22	38.36	39.46	40.51	41.50	42.45	3
4	28.06	29.49	30.87	32.23	33.54	34.82	36.05	37.23	38.38	39.47	40.52	41.52	42.46	4
5	28.08	29.51	30.90	32.25	33.57	34.84	36.07	37.25	38.40	39.49	40.54	41.54	42.48	5
6	28.10	29.53	30.92	32.27	33.59	34.86	36.09	37.27	38.41	39.51	40.55	41.55	42.49	6
7	28.13	29.56	30.94	32.30	33.61	34.88	36.11	37.29	38.43	39.51	40.57	41.57	42.51	7
8	28.15	29.58	30.97	32.32	33.63	34.90	36.13	37.31	38.45	39.55	40.59	41.58	42.53	8
9	28.18	29.60	30.99	32.34	33.65	34.92	36.15	37.33	38.47	39.56	40.61	41.60	42.54	9
10	28.20	29.62	31.01	32.36	33.67	34.94	36.17	37.35	38.49	39.58	40.62	41.61	42.56	10
11	28.22	29.65	31.04	32.39	33.70	34.96	36.19	37.37	38.52	39.60	40.64	41.63	42.58	11
12	28.25	29.67	31.06	32.41	33.72	34.98	36.21	37.39	38.53	39.61	40.66	41.65	42.59	12
13	28.27	29.69	31.08	32.43	33.74	35.00	36.23	37.41	38.55	39.63	40.68	41.67	42.60	13
14	28.30	29.72	31.10	32.45	33.76	35.02	36.25	37.43	38.56	39.65	40.69	41.68	42.62	14
15	28.32	29.74	31.13	32.47	33.78	35.05	36.27	37.45	35.58	39.67	40.71	41.70	42.64	15
16	28.34	29.76	31.15	32.49	33.80	35.07	36.29	37.47	38.60	39.69	40.72	41.71	42.65	16
17	28.37	29.79	31.17	32.51	33.82	35.09	36.31	37.49	38.62	39.71	40.74	41.73	42.66	17
18	28.39	29.81	31.19	32.54	33.84	35.11	36.33	37.51	38.64	39.72	40.76	41.74	42.68	18
19	28.42	29.83	31.22	32.56	33.87	35.13	36.35	37.53	38.66	39.74	40.78	41.76	42.70	19
20	28.44	29.86	31.24	32.58	33.89	35.15	36.37	37.54	38.67	39.76	40.79	41.77	42.71	20
21	28.47	29.88	31.26	32.61	33.91	35.17	36.39	37.56	38.69	39.78	40.81	41.79	42.72	21
22	28.49	29.90	31.28	32.63	33.93	35.19	36.41	37.58	38.71	39.79	40.82	41.81	42.74	22
23	28.51	29.93	31.30	32.65	33.95	35.21	36.43	37.60	38.73	39.82	40.84	41.83	42.76	23
24	28.54	29.95	31.33	32.67	33.97	35.23	36.45	37.62	38.75	39.83	40.86	41.84	42.77	24
25	28.56	29.97	31.35	32.70	33.99	35.25	36.47	37.64	38.76	39.85	40.88	41.86	42.78	25
26	28.58	30.00	31.38	32.72	34.01	35.27	36.49	37.66	38.78	39.86	40.89	41.87	42.80	26
27	28.61	30.02	31.40	32.74	34.04	35.29	36.51	37.68	38.80	39.88	40.91	41.89	42.82	27
28	28.63	30.04	31.42	32.76	34.06	35.31	36.53	37.70	38.82	39.90	40.92	41.90	42.83	28
29	28.66	30.07	31.43	32.78	34.08	35.34	36.55	37.72	38.84	39.92	20.94	41.92	42.85	29
30	28.68	30.09	31.47	32.80	34.10	35.36	36.57	37.74	38.86	39.93	40.96	41.93	42.86	30
31	28.70	30.11	31.49	32.83	34.12	35.38	36.59	37.76	38.88	39.95	40.98	41.95	42.88	31
32	28.73	30.14	31.51	32.85	34.14	35.40	36.61	37.77	38.89	39.97	40.99	41.97	42.89	32
33	28.75	30.16	31.54	32.87	34.16	35.42	36.63	37.79	38.91	39.99	41.01	41.99	42.91	33
34	28.77	30.19	31.56	32.89	34.18	35.44	36.65	37.81	38.93	40.00	41.02	42.00	42.92	34
35	28.80	30.21	31.58	32.91	34.21	35.46	36.67	37.83	38.95	40.02	41.04	42.02	42.94	35
36	28.82	30.23	31.60	32.93	34.23	35.48	36.69	37.85	38.97	40.04	41.06	42.03	42.95	36
37	28.85	30.26	31.63	32.96	34.25	35.50	36.71	37.87	38.99	40.06	41.08	42.05	42.97	37
38	28.87	30.28	31.65	32.98	34.27	35.52	36.73	37.89	39.00	40.07	41.09	42.06	42.98	38
39	28.89	30.30	31.67	33.00	34.29	35.54	36.75	37.91	39.02	40.09	41.11	42.08	43.00	39
40	28.92	30.32	31.69	33.02	34.31	35.56	36.77	37.93	39.04	40.11	41.12	42.09	43.01	40
41	28.94	30.36	31.72	33.05	34.33	35.58	36.79	37.95	39.06	40.13	41.14	42.11	43.03	41
42	28.96	30.37	31.74	33.07	34.35	35.60	36.80	37.96	39.08	40.14	41.16	42.12	43.04	42
43	28.99	30.39	31.76	33.09	34.38	35.62	36.82	37.98	39.10	40.16	41.18	42.14	43.06	43
44	29.01	30.41	31.78	33.11	34.40	35.64	36.84	38.00	39.11	40.18	41.19	42.15	43.07	44
45	29.04	30.44	31.81	33.13	34.42	35.66	36.86	38.02	39.13	40.20	41.21	42.17	43.09	45
46	29.06	30.46	31.83	33.15	34.44	35.68	36.88	38.04	39.15	40.21	41.22	42.19	43.10	46
47	29.08	30.49	31.85	33.18	34.46	35.70	36.90	38.06	39.17	40.23	41.24	42.21	43.12	47
48	29.11	30.51	31.87	33.20	34.48	35.72	36.92	38.08	39.18	40.24	41.26	42.22	43.13	48
49	29.13	30.53	31.90	33.32	34.50	35.74	36.94	38.10	39.20	40.26	41.28	42.24	43.15	49
50	29.15	30.55	31.92	33.24	34.52	35.76	36.96	38.11	39.22	40.28	41.29	42.25	43.16	50
51	29.18	30.58	31.94	33.26	34.54	35.78	36.98	38.13	39.24	40.30	41.31	42.26	43.17	51
52	29.20	30.60	31.96	33.28	34.57	35.80	37.00	38.15	39.26	40.31	41.32	42.28	43.18	52
53	29.23	30.62	31.99	33.31	34.59	35.83	37.02	38.17	39.27	40.33	41.34	42.30	43.20	53
54	29.25	30.65	32.01	33.33	34.61	35.85	37.04	38.19	39.29	40.35	41.35	42.31	43.21	54
55	29.27	30.67	32.02	33.35	34.63	35.87	37.06	38.21	39.31	40.37	41.37	42.33	43.23	55
56	29.30	30.69	32.05	33.37	34.65	35.89	37.08	38.23	39.33	40.38	41.39	42.34	43.24	56
57	29.32	30.72	32.07	33.39	34.67	35.91	37.10	38.25	39.35	40.40	41.41	42.36	43.26	57
58	29.34	30.74	32.09	33.41	34.69	35.93	37.12	38.26	39.36	40.42	41.42	42.37	43.27	58
59	29.37	30.76	32.12	33.44	34.71	35.95	37.14	38.28	39.38	40.44	41.43	42.39	43.29	59
Horz. Dist.	90.06	89.93	88.86	87.74	86.57	85.36	84.10	82.80	81.47	80.09	78.68	77.23	75.75	Horz. Dist.

Conversion of Feet to Decimals of a Mile

Feet	Mile	Feet	Mile	Feet	Mile	Feet	Mile	Feet	Mile	Feet	Mile	Feet	Mile
100	0.019	600	0.114	1100	0.208	1600	0.303	2100	0.398	2600	0.492	3100	0.587
110	0.021	610	0.116	1110	0.210	1610	0.305	2110	0.400	2610	0.494	3110	0.589
120	0.023	620	0.118	1120	0.212	1620	0.307	2120	0.402	2620	0.496	3120	0.591
130	0.025	630	0.120	1130	0.214	1630	0.309	2130	0.404	2630	0.498	3130	0.593
140	0.026	640	0.122	1140	0.216	1640	0.311	2140	0.405	2640	0.500	3140	0.595
150	0.028	650	0.124	1150	0.218	1650	0.313	2150	0.407	2650	0.502	3150	0.596
160	0.030	660	0.125	1160	0.219	1660	0.314	2160	0.409	2660	0.504	3160	0.598
170	0.032	670	0.127	1170	0.221	1670	0.316	2170	0.411	2670	0.506	3170	0.600
180	0.034	680	0.129	1180	0.223	1680	0.318	2180	0.413	2680	0.508	3180	0.602
190	0.036	690	0.131	1190	0.225	1690	0.320	2190	0.415	2690	0.509	3190	0.604
200	0.038	700	0.133	1200	0.227	1700	0.322	2200	0.417	2700	0.511	3200	0.606
210	0.040	710	0.134	1210	0.229	1710	0.324	2210	0.419	2710	0.513	3210	0.608
220	0.042	720	0.136	1220	0.231	1720	0.326	2220	0.420	2720	0.515	3220	0.610
230	0.044	730	0.138	1230	0.233	1730	0.328	2230	0.422	2730	0.517	3230	0.612
240	0.046	740	0.140	1240	0.235	1740	0.330	2240	0.424	2740	0.519	3240	0.614
250	0.047	750	0.142	1250	0.236	1750	0.331	2250	0.426	2750	0.521	3250	0.616
260	0.049	760	0.144	1260	0.238	1760	0.333	2260	0.428	2760	0.523	3260	0.617
270	0.051	770	0.146	1270	0.240	1770	0.335	2270	0.430	2770	0.525	3270	0.619
280	0.053	780	0.148	1280	0.242	1780	0.337	2280	0.432	2780	0.527	3280	0.621
290	0.055	790	0.150	1290	0.244	1790	0.339	2290	0.434	2290	0.529	3290	0.623
300	0.057	800	0.152	1300	0.246	1800	0.341	2300	0.436	2800	0.530	3300	0.625
310	0.059	810	0.153	1310	0.248	1810	0.343	2310	0.438	2810	0.532	3310	0.627
320	0.061	820	0.155	1320	0.250	1820	0.345	2320	0.439	2820	0.534	3320	0.629
330	0.062	830	0.157	1330	0.252	1830	0.347	2330	0.441	2830	0.536	3330	0.631
340	0.064	840	0.159	1340	0.254	1840	0.349	2340	0.443	2840	0.538	3340	0.633
350	0.066	850	0.161	1350	0.256	1850	0.350	2350	0.445	2850	0.540	3350	0.644
360	0.068	860	0.163	1360	0.257	1860	0.352	2260	0.447	2860	0.542	3360	0.666
370	0.070	870	0.165	1370	0.259	1870	0.354	2370	0.449	2870	0.544	3370	0.688
380	0.072	880	0.167	1380	0.261	1880	0.356	2380	0.451	2880	0.546	3380	0.640
390	0.074	890	0.169	1390	0.263	1890	0.358	2390	0.453	2890	0.547	3390	0.642
400	0.076	900	0.170	1400	0.265	1900	0.360	2400	0.455	2900	0.549	3400	0.644
410	0.078	910	0.172	1410	0.267	1910	0.362	2410	0.456	2910	0.551	3410	0.646
420	0.080	920	0.174	1420	0.269	1920	0.364	2420	0.458	2920	0.553	3420	0.648
430	0.082	930	0.176	1430	0.271	1930	0.366	2430	0.460	2930	0.555	3430	0.650
440	0.084	940	0.178	1440	0.273	1940	0.367	2440	0.462	2940	0.557	3440	0.652
450	0.086	950	0.180	1450	0.275	1950	0.369	2450	0.464	2950	0.559	3450	0.653
460	0.088	960	0.181	1460	0.276	1960	0.371	2460	0.466	2960	0.561	3460	0.655
470	0.089	970	0.183	1470	0.278	1970	0.373	2470	0.468	2970	0.562	3470	0.657
480	0.091	980	0.185	1480	0.280	1980	0.375	2480	0.470	2980	0.564	3480	0.659
490	0.093	990	0.187	1490	0.282	1990	0.377	2490	0.472	2990	0.566	3490	0.661
500	0.095	1000	0.189	1500	0.284	2000	0.379	2500	0.474	3000	0.568	3500	0.663
510	0.097	1010	0.191	1510	0.286	2010	0.381	2510	0.475	3010	0.570	3510	0.665
520	0.098	1020	0.193	1520	0.288	2020	0.383	2520	0.477	3020	0.572	3520	0.667
530	0.100	1030	0.195	1530	0.290	2030	0.384	2530	0.479	3030	0.574	3530	0.669
540	0.102	1040	0.197	1540	0.292	2040	0.386	2540	0.481	3040	0.576	3540	0.670
550	0.104	1050	0.199	1550	0.294	2050	0.388	2550	0.483	3050	0.578	3550	0.672
560	0.106	1060	0.200	1560	0.295	2060	0.390	2560	0.485	3060	0.580	3560	0.674
570	0.108	1070	0.202	1570	0.297	2070	0.392	2570	0.487	3070	0.581	3570	0.676
580	0.110	1080	0.204	1580	0.299	2080	0.394	2580	0.489	3080	0.583	3580	0.678
590	0.112	1090	0.206	1590	0.301	2090	0.396	2590	0.491	3090	0.585	3590	0.680

Table IV.—Gradienter Table for the Determination of Distances

Number of gradienter divisions	Rod intercept										Number of gradienter divisions
	1	2	3	4	5	6	7	8	9	10	
10	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	10
11	909	1,818	2,727	3,636	4,545	5,455	6,364	7,273	8,182	9,091	11
12	833	1,667	2,500	3,333	4,167	5,000	5,833	6,667	7,500	8333,	12
13	769	1,538	2,308	3,077	3,846	4,615	5,384	6,154	6,923	7,692	13
14	714	1,429	2,143	2,857	3,571	4,286	5,000	5,714	6,429	7,143	14
15	667	1,333	2,000	2,667	3,333	4,000	4,667	5,333	6,000	6,667	15
16	625	1,250	1,875	2,500	3,125	3,750	4,375	5,000	5,625	6,250	16
17	588	1,176	1,765	2,353	2,941	3,529	4,110	4,706	5,294	5,882	17
18	556	1,111	1,667	2,222	2,778	3,333	3,889	4,444	5,000	5,556	18
19	526	1,053	1,579	2,105	2,632	3,158	3,684	4,211	4,737	5,263	19
20	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	20
21	476	952	1,429	1,905	2,381	2,857	3,333	3,810	4,286	4,762	21
22	455	909	1,364	1,818	2,273	2,727	3,182	3,636	4,091	4,545	22
23	435	870	1,304	1,739	2,174	2,609	3,043	3,478	3,913	4,348	23
24	417	833	1,250	1,667	2,083	2,500	2,917	3,333	3,750	4,167	24
25	400	800	1,200	1,600	2,000	2,400	2,800	3,200	3,600	4,000	25
26	385	769	1,154	1,538	1,923	2,308	2,692	3,077	3,462	3,846	26
27	370	741	1,111	1,481	1,852	2,222	2,593	2,963	3,333	3,704	27
28	357	714	1,071	1,429	1,786	2,143	2,500	2,857	3,214	3,571	28
29	345	690	1,035	1,379	1,724	2,069	2,414	2,759	3,103	3,448	29
30	333	667	1,000	1,333	1,667	2,000	2,333	2,667	3,000	3,333	30
31	323	645	968	1,290	1,613	1,935	2,258	2,581	2,903	3,226	31
32	313	625	938	1,250	1,563	1,875	2,188	2,500	2,813	3,125	32
33	303	606	909	1,212	1,515	1,818	2,121	2,424	2,727	3,030	33
34	294	588	882	1,176	1,471	1,765	2,059	2,353	2,647	2,941	34
35	286	571	857	1,143	1,429	1,714	2,000	2,286	2,571	2,857	35
36	278	556	833	1,111	1,389	1,667	1,944	2,222	2,500	2,778	36
37	270	541	811	1,081	1,351	1,622	1,892	2,162	2,432	2,703	37
38	263	526	789	1,053	1,316	1,579	1,842	2,105	2,368	2,632	38
39	256	513	769	1,026	1,282	1,538	1,795	2,051	2,308	2,564	39
40	250	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	40
41	244	488	732	976	1,220	1,463	1,707	1,951	2,195	2,439	41
42	238	476	714	952	1,190	1,429	1,667	1,905	2,143	2,381	42
43	233	465	698	930	1,163	1,395	1,628	1,860	2,093	2,326	43
44	227	455	682	909	1,136	1,364	1,591	1,818	2,045	2,273	44
45	222	444	667	889	1,111	1,333	1,556	1,778	2,000	2,222	45
46	217	435	652	870	1,087	1,304	1,522	1,739	1,957	2,174	46
47	213	426	638	851	1,064	1,277	1,489	1,702	1,915	2,128	47
48	208	417	625	833	1,042	1,250	1,458	1,667	1,875	2,083	48
49	204	408	612	816	1,020	1,224	1,429	1,633	1,837	2,041	49
50	200	400	600	800	1,000	1,200	1,400	1,600	1,800	2,000	50

TABLE IV.—GRADIENTER TABLE FOR THE DETERMINATION OF DISTANCES (*Continued*)

Number of gradienter divisions	Rod intercept										Number of gradienter divisions
	11	12	13	14	15	16	17	18	19	20	
10	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000	10
11	10,000	10,909	11,818	12,727	13,636	14,545	15,455	16,364	17,273	18,182	11
12	9,167	10,000	10,833	16,667	12,500	13,333	14,167	15,000	15,833	16,667	12
13	8,462	9,231	10,000	10,769	11,538	12,308	13,077	13,846	14,615	15,385	13
14	7,857	8,571	9,286	10,000	10,714	11,429	12,143	12,857	13,571	14,286	14
15	7,333	8,000	8,667	9,333	10,000	10,667	11,333	12,000	12,667	13,333	15
16	6,875	7,500	8,125	8,750	9,375	10,000	10,625	11,250	11,875	12,500	16
17	6,471	7,059	7,647	8,235	8,824	9,412	10,000	10,588	11,176	11,765	17
18	6,111	6,667	7,222	7,778	8,333	8,889	9,444	10,000	10,556	11,111	18
19	5,789	6,316	6,842	7,368	7,895	8,421	8,947	9,474	10,000	10,526	19
20	5,500	6,000	6,500	7,000	7,500	8,000	8,500	9,000	9,500	10,000	20
21	5,238	5,714	6,190	6,667	7,143	7,619	8,095	8,571	9,048	9,524	21
22	5,000	5,455	5,909	6,364	6,818	7,273	7,727	8,182	8,636	9,091	22
23	4,783	5,217	5,652	6,087	6,522	6,957	7,391	7,826	8,261	8,696	23
24	4,583	5,000	5,417	5,833	6,250	6,667	7,083	7,500	7,917	8,333	24
25	4,400	4,800	5,200	5,600	6,000	6,400	6,800	7,200	7,600	8,000	25
26	4,231	4,615	5,000	5,385	5,769	6,154	6,538	6,923	7,308	7,692	26
27	4,074	4,444	4,815	5,185	5,556	5,926	6,296	6,667	7,037	7,407	27
28	3,929	4,286	4,643	5,000	5,357	5,714	6,071	6,429	6,786	7,143	28
29	3,793	4,138	4,483	4,828	5,172	5,517	5,862	6,207	6,552	6,897	29
30	3,667	4,000	4,333	4,667	5,000	5,333	5,667	6,000	6,333	6,667	30
31	3,548	3,871	4,194	4,516	4,839	5,161	5,484	5,806	6,129	6,452	31
32	3,438	3,750	4,063	4,375	4,688	5,000	5,313	5,625	5,938	6,250	32
33	3,333	3,636	3,939	4,242	4,545	4,848	5,152	5,455	5,758	6,061	33
34	3,235	3,529	3,824	4,118	4,412	4,706	5,000	5,294	5,588	5,882	34
35	3,143	3,429	3,714	4,000	4,286	4,571	4,857	5,143	5,429	5,714	35
36	3,056	3,333	3,611	3,889	4,167	4,444	4,722	5,000	5,278	5,556	36
37	2,973	3,243	3,514	3,784	4,054	4,324	4,595	4,865	5,135	5,405	37
38	2,895	3,158	3,421	3,684	3,947	4,211	4,474	4,737	5,000	5,263	38
39	2,820	3,077	3,333	3,590	3,846	4,102	4,359	4,615	4,872	5,128	39
40	2,750	3,000	3,250	3,500	3,750	4,000	4,250	4,500	4,750	5,000	40
41	2,683	2,927	3,171	3,415	3,659	3,902	4,146	4,390	4,634	4,878	41
42	2,619	2,857	3,095	3,333	3,571	3,810	4,048	4,286	4,524	4,762	42
43	2,558	2,791	3,023	3,256	3,488	3,721	3,953	4,186	4,419	4,651	43
44	2,500	2,727	2,954	3,182	3,409	3,636	3,864	4,091	4,318	4,545	44
45	2,444	2,667	2,889	3,111	3,333	3,555	3,778	4,000	4,222	4,444	45
46	2,391	2,609	2,826	3,043	3,261	3,478	3,696	3,913	4,130	4,348	46
47	2,340	2,553	2,766	2,979	3,191	3,404	3,617	3,830	4,043	4,255	47
48	2,292	2,500	2,708	2,917	3,125	3,333	3,542	3,750	3,958	4,167	48
49	2,245	2,449	2,653	2,857	3,061	3,265	3,469	3,673	3,878	4,082	49
50	2,200	2,400	2,600	2,800	3,000	3,200	3,400	3,600	3,800	4,000	50

Table V.—Table for Determining Horizontal Distances by Means of the Vertical Arc

Minutes of arc	Percentage of one stadia angle	Rod intercept in feet									
		6	7	8	9	10	11	12	13	14	15
1	2.908	20,632	24,071	27,510	30,948	34,387	37,826	41,264	44,703	48,142	51,581
2	5.817	10,314	12,033	13,752	15,471	17,190	18,909	20,628	22,347	24,066	25,785
3	8.725	6,877	8,023	9,169	10,315	11,461	12,607	13,753	14,899	16,045	17,192
4	11.633	5,758	6,017	6,877	7,736	8,596	9,456	10,315	11,175	12,034	12,894
5	14.542	4,126	4,813	5,501	6,188	6,876	7,564	8,251	8,939	9,626	10,314
6	17.450	3,438	4,011	4,584	5,157	5,730	6,303	6,876	7,449	8,022	8,595
7	20.358	2,947	3,438	3,930	4,421	4,912	5,403	5,894	6,386	6,877	7,368
8	23.266	2,579	3,009	3,438	3,868	4,298	4,728	5,158	5,587	6,017	6,447
9	26.175	2,292	2,674	3,056	3,438	3,820	4,202	4,584	4,966	5,248	5,730
10	29.083	2,063	2,407	2,750	3,094	3,438	3,782	4,126	4,469	4,813	5,157
11	31.991	1,875	2,188	2,500	2,813	3,125	3,438	3,550	4,063	4,375	4,688
12	34.899	1,719	2,006	2,292	2,579	2,865	3,152	3,438	3,725	4,011	4,298
13	37.807	1,587	1,852	2,116	2,381	2,645	2,910	3,174	3,438	3,703	3,968
14	40.715	1,474	1,719	1,965	2,210	2,456	2,702	2,947	3,193	3,438	3,684
15	43.623	1,375	1,604	1,834	2,063	2,292	2,521	2,750	2,980	3,209	3,438
16	46.531	1,289	1,504	1,718	1,933	2,148	2,363	2,578	2,792	3,007	3,222
17	49.439	1,213	1,415	1,618	1,820	2,022	2,224	2,426	2,629	2,831	3 033

Explanation for Table VI

Explanation of tables for temperature correction for altitude scales:

Illustration.—At the bottom of a mountain the temperature is 70°F., and the hand on the barometer points to 2000 ft. The correction as noted at 70° is 82 ft. which has to be added, as have all temperature corrections above 50°F., making the reading 2082.

If at the top of the mountain the reading is 6000 ft. and the temperature is 20° the correction will be 367 ft. and is to be subtracted making the reading 5633.

Table VI.—Temperature Corrections for Altitude Scales

Smithsonian Miscellaneous Collection No. 21.
For temperatures above 50°F. the values are to be added.
For temperatures below 50°F. the values are to be subtracted.

Temperature, degrees Fahrenheit		Feet of altitude					
		100	500	1000	2000	3000	4000
49	51	0	1	2	4	6	8
48	52	0	2	4	8	12	16
47	53	1	3	6	12	18	24
46	54	1	4	8	16	24	33
45	55	1	5	10	20	31	41
44	56	1	6	12	24	37	49
43	57	1	7	14	29	43	57
42	58	2	8	16	33	49	65
41	59	2	9	18	37	55	73
40	60	2	10	20	41	61	82
39	61	2	11	22	45	67	90
38	62	2	12	24	49	73	98
37	63	3	13	27	53	80	106
36	64	3	14	29	57	86	114
35	65	3	15	31	61	92	122
34	66	3	16	33	65	98	130
33	67	3	17	35	69	104	139
32	68	4	18	37	73	110	147
31	69	4	19	39	77	116	155
30	70	4	20	41	82	122	163
29	71	4	21	43	86	128	171
28	72	4	22	45	90	135	179
27	73	5	23	47	94	141	188
26	74	5	24	49	98	147	196
25	75	5	25	51	102	153	204
24	76	5	27	53	106	159	212
23	77	6	28	55	110	165	220
22	78	6	29	57	114	171	228
21	79	6	30	59	118	177	236
20	80	6	31	61	122	184	245
19	81	6	32	63	126	190	253
18	82	7	33	65	130	196	261
17	83	7	34	67	135	202	269
16	84	7	35	69	139	208	277
15	85	7	36	71	143	214	285
14	86	7	37	73	147	220	294
13	87	8	38	75	151	226	302
12	88	8	39	77	155	232	310
11	89	8	40	80	159	239	318
10	90	8	41	82	163	245	326
9	91	8	42	84	167	251	334
8	92	9	43	86	171	257	343
7	93	9	44	88	175	263	351
6	94	9	45	90	179	269	359
5	95	9	46	92	184	275	367
4	96	9	47	94	188	281	375
3	97	10	48	96	192	287	383
2	98	10	49	98	196	294	391
1	99	10	50	100	200	300	400
0	100	10	51	102	204	306	408

See preceding page for explanation of table.

TABLE VI.—TEMPERATURE CORRECTIONS FOR ALTITUDE SCALES (*Continued*)

Smithsonian Miscellaneous Collection No. 21.
For temperatures above 50°F. the values are to be added.
For temperatures below 50°F. the values are to be subtracted.

Temperature, degrees Fahrenheit		Feet of altitude					
		5000	6000	7000	8000	9000	10,000
49	51	10	12	14	16	18	20
48	52	20	24	29	33	37	41
47	53	31	37	43	49	55	61
46	54	41	49	57	65	73	82
45	55	51	61	71	82	92	102
44	56	61	73	86	98	110	122
43	57	71	86	100	114	128	143
42	58	82	98	114	130	147	163
41	59	92	110	128	147	165	184
40	60	102	122	143	163	184	204
39	61	112	135	157	179	202	224
38	62	122	147	171	196	220	245
37	63	133	159	186	212	239	265
36	64	143	171	200	228	257	285
35	65	153	184	214	245	275	306
34	66	163	196	228	261	294	326
33	67	173	208	243	277	312	347
32	68	184	220	257	294	330	367
31	69	194	232	271	310	349	387
30	70	204	245	285	326	367	408
29	71	214	257	300	343	385	428
28	72	224	269	314	359	404	449
27	73	234	281	328	375	422	469
26	74	245	294	343	391	440	489
25	75	255	306	357	408	459	510
24	76	265	318	371	424	477	530
23	77	275	330	385	440	495	551
22	78	285	343	400	457	514	571
21	79	296	355	414	473	532	591
20	80	306	367	428	489	551	612
19	81	316	379	442	506	569	632
18	82	326	391	457	522	587	652
17	83	336	404	471	538	606	673
16	84	347	416	485	555	624	693
15	85	357	428	500	571	642	714
14	86	367	440	514	587	661	734
13	87	377	453	528	604	679	754
12	88	387	465	542	620	697	775
11	89	398	477	557	636	716	795
10	90	408	489	571	652	734	816
9	91	418	502	585	669	752	836
8	92	428	514	599	685	771	856
7	93	438	526	614	701	789	877
6	94	449	538	628	718	807	897
5	95	459	551	642	734	826	918
4	96	469	563	657	750	844	938
3	97	479	575	671	767	862	958
2	98	489	587	685	783	881	979
1	99	500	599	699	799	899	999
0	100	510	612	714	816	918	1020

Table VII.—Airey's Table for the Determination of Altitude by Means of the Barometer*

Aneroid or corrected barometer, inches	Height in feet	Aneroid or corrected barometer, inches	Height in feet	Aneroid or corrected barometer, inches	Height in feet	Aneroid or corrected barometer, inches	Height in feet	Aneroid or corrected barometer, inches	Height in feet
31.00	0	28.28	2500	25.80	5000	23.54	7500	21.47	10,000
30.94	50	28.23	2550	25.75	5050	23.50	7550	21.44	10,050
30.88	100	28.18	2600	25.71	5100	23.45	7600	21.40	10,100
30.83	150	28.12	2650	25.66	5150	23.41	7650	21.36	10,150
30.77	200	28.07	2700	25.61	5200	23.37	7700	21.32	10,200
30.71	250	28.02	2750	25.56	5250	23.32	7750	21.28	10,250
30.66	300	27.97	2800	25.52	5300	23.28	7800	21.24	10,300
30.60	350	27.92	2850	25.47	5350	23.24	7850	21.20	10,350
30.54	400	27.87	2900	25.42	5400	23.20	7900	21.16	10,400
30.49	450	27.82	2950	25.38	5450	23.15	7950	21.12	10,450
30.43	500	27.76	3000	25.33	5500	23.11	8000	21.08	10,500
30.38	550	27.71	3050	25.28	5550	23.07	8050	21.05	10,550
30.32	600	27.66	3100	25.24	5600	23.03	8100	21.01	10,600
30.26	650	27.61	3150	25.19	5650	22.98	8150	20.97	10,650
30.21	700	27.56	3200	25.15	5700	22.94	8200	20.93	10,700
30.15	750	27.51	3250	25.10	5750	22.90	8250	20.89	10,750
30.10	800	27.46	3300	25.05	5800	22.86	8300	20.85	10,800
30.04	850	27.41	3350	25.01	5850	22.82	8350	20.82	10,850
29.99	900	27.36	3400	24.96	5900	22.77	8400	20.78	10,900
29.93	950	27.31	3450	24.92	5950	22.73	8450	20.74	10,950
29.88	1000	27.26	3500	24.87	6000	22.69	8500	20.70	11,000
29.82	1050	27.21	3550	24.82	6050	22.65	8550	20.66	11,050
29.77	1100	27.16	3600	24.78	6100	22.61	8600	20.63	11,100
29.71	1150	27.11	3650	24.73	6150	22.57	8650	20.59	11,150
29.66	1200	27.06	3700	24.69	6200	22.52	8700	20.55	11,200
29.61	1250	27.01	3750	24.64	6250	22.48	8750	20.51	11,250
29.55	1300	26.96	3800	24.60	6300	22.44	8800	20.47	11,300
29.50	1350	26.91	3850	24.55	6350	22.40	8850	20.44	11,350
29.44	1400	26.86	3900	24.51	6400	22.36	8900	20.40	11,400
29.39	1450	26.81	3950	24.46	6450	22.32	8950	20.36	11,450
29.34	1500	26.76	4000	24.42	6500	22.28	9000	20.32	11,500
29.28	1550	26.72	4050	24.37	6550	22.24	9050	20.29	11,550
29.23	1600	26.67	4100	24.33	6600	22.20	9100	20.25	11,600
29.17	1650	26.62	4150	24.28	6650	22.16	9150	20.21	11,650
29.12	1700	26.57	4200	24.24	6700	22.11	9200	20.18	11,700
29.07	1750	26.52	4250	24.20	6750	22.07	9250	20.14	11,750
29.01	1800	26.47	4300	24.15	6800	22.03	9300	20.10	11,800
28.96	1850	26.42	4350	24.11	6850	21.99	9350	20.07	11,850
28.91	1900	26.37	4400	24.06	6900	21.95	9400	20.03	11,900
28.86	1950	26.33	4450	24.02	6950	21.91	9450	19.99	11,950
28.80	2000	26.28	4500	23.97	7000	21.87	9500	19.95	12,000
28.75	2050	26.23	4550	23.93	7050	21.83	9550	19.241	13,000
28.70	2100	26.18	4600	23.89	7100	21.79	9600	18.548	14,000
28.64	2150	26.13	4650	23.84	7150	21.75	9650	17.880	15,000
28.59	2200	26.09	4700	23.80	7200	21.71	9700	17.235	16,000
28.54	2250	26.04	4750	23.76	7250	21.67	9750	16.615	17,000
28.49	2300	25.99	4800	23.71	7300	21.63	9800	16.016	18,000
28.43	2350	25.94	4850	23.67	7350	21.59	9850	15.439	19,000
28.38	2400	25.89	4900	23.62	7400	21.55	9900	14.883	20,000
28.33	2450	25.85	4950	23.58	7450	21.51	9950		

* After P. R. Jameson.

TABLE VIII.—CONVENTIONAL SYMBOLS

Stations

Symbol	Meaning
×	Location or station
	Turning point
△	Instrument station

Elevations

Symbol	Meaning
B.M x 1232	Bench mark
967	Elevation of outcrop at station
(846)	Elevation reduced to common datum plane

Land lines

Symbol	Meaning
———	Section line
	Section corner
— — —	Township line

Water

Symbol	Meaning
	Spring
	Intermittent stream or drainage course
	Stream
	Lake or pond
	Swamp or marsh

Culture

Symbol	Meaning
□	House
	Church
	School
- - -	Fence
═══	Road
::::::	Private road
+++	Railroad
	Cemetery
⚒	Mine or quarry

Wells

Symbol	Meaning
○	Location
⊙	Well drilling
●	Oil well
	Gas well
	Dry well
	Water in sand
	Oil and water
	Gas, oil and water
	Show of oil
	Show of gas
⌀	Location abandoned
	Oil well abandoned
	Gas well abandoned

TABLE IX.—TABLE OF ERAS AND PERIODS

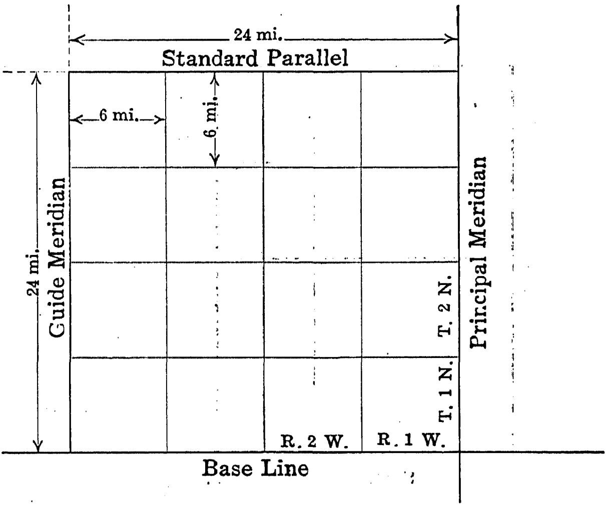
Era	*Period*	*Epoch*
Cenozoic		
	Quaternary	
		Recent
		Pleistocene
	Tertiary	
		Pliocene
		Miocene
		Oligocene
		Eocene
Mesozoic		
	Cretaceous	
	Jurassic	
	Triassic	
Paleozoic		
	Carboniferous	
		Permian
		Pennsylvanian
		Mississippian
	Devonian	
	Silurian	
	Ordovician	
	Cambrian	
Proterozoic		
	Algonkian	
		Keweenawan
		Huronian
	Archean	
		Laurentian
		Keewatin

In a number of the older states, such as Virginia, Kentucky, Louisiana, and Texas, the original surveys were by "metes and bounds," and no general system was recognized. Later a system of rectangular survey was adopted and is now in general use. This consists essentially of subdividing the country into quadrangles by guide meridians and standard parallels, 24 miles apart, beginning at a point where a principal meridian intersects a base line. The quadrangles thus formed are further subdivided into tracts six miles square called townships. These are numbered meridionally into ranges and latitudinally into townships, beginning at the initial point and numbering consecutively in the four cardinal directions.

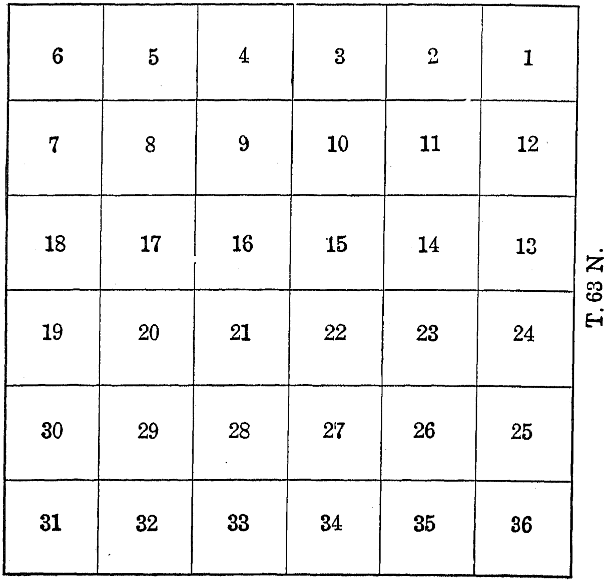
The township is further subdivided into 36 tracts one mile square, called sections. These are numbered consecutively, beginning at the northeast corner and proceeding to the west boundary line of the township, then south to the next tier and over to the east boundary line, continuing in this manner till all are numbered.

The section is subdivided into quarters and forties (see accompanying sketches, pp. 293-294) and numbered and designated according to the points of the compass. In some instances two forties may be referred to as a half of a quarter.

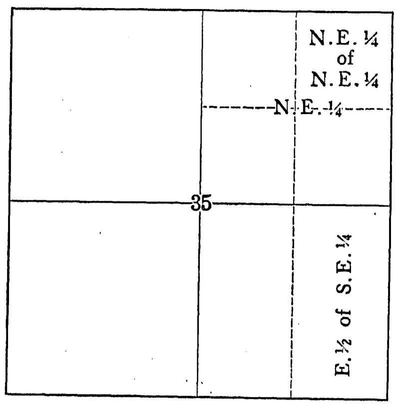
In referring to a given tract of land one would describe it as follows: the N. ½ NE. ¼ NW. ¼ sec. 36, T. 96 N., R. 43 W. In states where more than one principal meridian occurs the number of the meridian referred to must also be given.



The relation of townships and ranges to base line and principal meridian.



Township subdivisions.



Section subdivisions.

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